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APPLICATIONS OF ADVANCED V/STOL AIRCRAFT CONCEPTS TO CIVIL UTILITY MISSIONS

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Volume I

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16. Abstract The suitability of advanced V/STOL aircraft to civil utility applications was assessed for offshore oil support, forest fire support, transport, and humanitarian missions. The aircraft concepts considered in this study were a lift fan aircraft, a tilt rotor aircraft, and an advanced helicopter. All were civil variants of previously studied military multi-purpose aircraft. All the aircraft had a design payload of 2268 kg. (5000 lb.) with the maximum range varying from 3334 km. (1800 nm) for the lift fan STOL to 1482 km (800 nm) for the advanced helicopter. The analysis of these missions considered such factors as aircraft performance, annual utilization, initial cost, and operating cost. This study concluded that all the advanced V/STOL aircraft concepts generally performed these missions better than contemporary aircraft, especially where VTOL or STOL could be used to advantage. The lift fan aircraft and the tilt rotor aircraft were found to be very attractive for the offshore oil and the forest fire support missions. The lift fan aircraft in the VTOL mode was also found to be very attractive for the executive transport mission where the passenger time value was $30/hr. or more.

Volume II (NASA CR 151988) contains the Appendices to this report.

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TABLE OF CONTENTS

VOLUME I

TABLE OF CONTENTS (CONT'd)

TABLE OF CONTENTS

VOLUME II

APPENDICES

List of Figures

List of Figures (Cont'd.)

List of Tables

GLOSSARY OF TERMS

The following is a list of terms consisting of symbols, acronyms, and abbreviations used throughout this report.

TERMS	DEFINITION
APL	A Programming Language used in operator interactive mode
ASW	Anti-Submarine Warfare
BV	Boeing Vertol Company
CT	Rotor Thrust Coefficient
CTOL	Conventional Takeoff and Landing Aircraft
DOC	Direct Operating Costs
F	Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
ft	Feet
HESCOMP	Computer program to calculate the operational and economic parameters of a design helicopter
h	Altitude, feet (meters)
HLH	Heavy Lift Helicopter
hr	Hour
ISA	International Standard Day (Sea Level Pressure 29.92 Inches Mercury, Temperature 59 Degrees F)
IAS	Indicated Airspeed, Knots (meters per sec)
K	Thousands
kg	Kilogram
km	Kilometer
kt	Knot - Nautical Mile Per Hour
lb	Pounds (Mass)
M	Mach Number, ratio of aircraft velocity to velocity of sound (under same conditions)
MCAIR	McDonnell Aircraft Company
m	Meters

TERMS	DEFINITION
min	Minute (Time)
N/A	Not Applicable or Not Available
NASA	National Aeronautics and Space Administration
nm	Nautical Mile (6080 ft, 1852 m)
σ	Rotor Solidity
No.	Number
NRP	Normal Rated Power
RC	Rate of Climb, ft/min (m/min)
ROI	Return on Investment
SL	Sea Level or Short Landing
sm	Statute Mile
STO	Short Takeoff
USFS	U.S. Forest Service
UTTAS	Utility Tactical Transport Aircraft System
VASCOMP	Computer program to calculate the operational and economic parameters of a design aircraft
VL	Vertical Landing
V_{mc}	Maximum Cruise Speed, kts (m/sec)
V_{me}	Maximum Endurance Cruise Speed, kts (m/sec)
V_{mr}	Maximum Range Cruising Speed, kt (m/sec)
VOD	Vertical Onboard Delivery (Navy Mission)
V/STOL	Vertical or Short Takeoff and Landing Aircraft
VTO	Vertical Takeoff
$\overset{o}{W}_a$	Airflow Rate, lbs/sec (kg/sec)
W_{fc}	Fuel Flow Rate @ Normal Cruise, lbs/min (kg/min)
$\overset{o}{W}_{fcl}$	Fuel Flow Rate @ Climb, lbs per min (kg/min)
$\overset{o}{W}_{fh}$	Fuel Flow Rate @ Hover, lbs/min (kg/min)
$\overset{o}{W}_{fl}$	Fuel Flow Rate @ Loiter, lbs/min (kg/min)
$\overset{o}{W}_{fmc}$	Fuel Flow Rate @ Maximum Cruise Speed, lbs/min (kg/min)

TERMS	DEFINITION
$\overset{o}{W}_{fme}$	Fuel Flow Rate @ Maximum Endurance Cruise Speed, lbs/min (kg/min)
$\overset{o}{W}_{fmr}$	Fuel Flow Rate @ Maximum Range Cruise, lbs/min (kg/min)
$\overset{o}{W}_{fmrp}$	Fuel Flow Rate @ Maximum Rated Power, lbs/min (kg/min)
$\overset{o}{W}_{fto}$	Fuel Flow Rate @ Takeoff, lbs/min (kg/min)

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Finally, thanks are due to the NASA Ames personnel associated with this study. Mr. Jerry Barrack, the study monitor, provided the necessary guidance and valuable assistance in obtaining technical information from the Navy contractors. Mr. Darrell Wilcox assisted in his critical review of the study and by providing data developed in a study of offshore oil missions.

Keith R. Smith
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Project Manager

1. SUMMARY

This study, performed by The Aerospace Corporation, examines the potential worldwide civil utility applications of three advanced V/STOL aircraft concepts. Conceptual designs of a lift fan aircraft, a tilt rotor aircraft, and an advanced helicopter, originally evolved for Navy missions, are the subject of the study which was sponsored by the Research Aircraft Projects Office of the NASA Ames Research Center to provide a better understanding of the potential of these advanced V/STOL aircraft for civil mission applications. In this study, a number of missions were first established with their detailed mission parameters. The aircraft were then compared on the basis of their ability to meet the defined mission requirements and the economics associated with their use. The advanced design concepts were not only compared to each other, but also to contemporary aircraft currently performing similar missions. From the outset, it was assumed that an advanced helicopter would be produced eventually since it is an evolutionary design, very much like current designs going into production. The tilt rotor and lift fan aircraft, on the other hand, are more advanced and offer substantially greater performance; however, their development will depend upon the demonstrated capability of experimental aircraft. Therefore, this study understakes to show potential civil applications possible for the proposed military aircraft.

The NASA Ames Research Center has monitored the study, selected the specific aircraft, and provided technical data relative to the aircraft designs. The aircraft configurations studied are civil derivations of designs by McDonnel Aircraft Company and the Boeing Vertol Aircraft Company who provided interpretations of their design data and additional design details as required. All three aircraft designs are capable of carrying 23 passengers, or 5000 lb (2268 kg), for their design range. Top cruise speeds range from 180 kts (93 m/sec) for the helicopter to 300 kts (154 m/sec) for the tilt rotor, and to 480 kts (246 m/sec) for the lift fan aircraft. Operation ranges vary from approximately 800 nm (1482 km) for the advanced helicopter to 1400 nm (2593 km) for the tilt rotor, and to 1800 nm (3334 km) for the lift fan (STOL).

Missions analyzed were limited to real missions being performed today, for the most part, for which some quantitative data were available. Although a wide range of missions were initially conceptualized for study, the requirement for quantitative data guided the study to consider contemporary helicopter missions, particularly those which might benefit from the higher speeds and long ranges associated with fixed-wing aircraft (e.g., fire control and executive transport). For all but one mission (the humanitarian mission), quantitative data are available.

The costs of the operations were compared by using current modes of performing the mission as a baseline. The purchase costs for the new concept aircraft were ~~predicated~~ premised on the military paying for the majority of their research and development costs. Development costs for the civil versions were taken to be those associated with a few modifications and the civil certification. Other operating cost factors were developed as required to describe the total costs of operation.

This study employed a computer program to define aircraft and missions in a standard format, and to analyze aircraft performance relative to themissions. This permitted the missions to be examined parametrically by changing the mission parameters (payload and range) over a broad spectrum in order to determine their effects on mission time and costs.

Currently, a total of 25 missions are defined for helicopters by the Helicopter Association of America. Since emphasis in this study has been directed to utility missions, those missions associated with scheduled air commuter and scheduled air carrier operations have not been analyzed. A number of the listed missions were eliminated from detailed consideration because the study constrained the aircraft size to only the 5000 lb (2268 kg) payload designs. For most of these missions, this payload capacity was too large. However, smaller derivative aircraft may be economically viable for these missions and deserve consideration in future studies. Missions requiring external load work and extensive hovering, such as logging and construction work, were considered as being generally inappropriate for the lift fan aircraft, and possibly so for the tilt rotor. Therefore, these utility

missions were not examined further. Some of the missions listed were similar to others on the list (e.g., executive transport and air taxi); they were, therefore, combined and examined under one mission classification.

In view of the foregoing, the study was focused on the following four civil utility missions:

a. The offshore oil support mission which carries oil drilling and production crews between shore bases and the drilling or production platforms.

b. The forest fire fighting and support mission which transports men and material to fire zones, and drops fire retardant materials onto forest fires.

c. The unscheduled personnel transport mission which transports corporate executives by company-owned planes, or other passengers by air taxi operators for hire.

d. The humanitarian mission which conducts rescue and relief flights to large-scale disaster areas where fixed-wing aircraft cannot effectively operate.

The study indicates that both the lift fan and the tilt rotor aircraft are outstanding performers in the offshore oil mission. They provide a range/payload capability well beyond that required, and complete the mission quickly - compared to today's helicopters. They demonstrate, generally, an excess range capability which tends to make these aircraft more expensive than necessary for this mission; however, this fact does not detract materially from their application in this mission. If a redesign to reduce the range by approximately one-half while still retaining the same payload could make it possible to significantly reduce the initial cost and operating expenses, then an aircraft better matching the offshore oil mission would result. However, this change would not necessarily be favorable for fire missions. These missions operate mostly at shorter ranges, and the reduction in fuel requirements allows increased payloads.

The lift fan aircraft and tilt rotor can open new areas of utility in the fire control mission by operating as high-capacity, short-range VTOL aerial tankers. They can be remotely deployed in order to provide coverage to large, potential fire areas. Because of their high speed, they can respond quickly, once a fire is spotted. Using their VTOL capability, they are able to pick up and carry large retardant loads from short-range, advanced fire bases set up to fight the fire. Thus, they combine in one machine the capabilities of the current fixed-wing aerial tanker and the helicopter, and do it quicker, decidedly an advantage in fire fighting.

The 23-passenger V/STOL aircraft examined by this study are generally too large for the executive transport missions, where the typical passenger load average is less than eight. Assuming these advanced aircraft concepts have been proven in other missions, smaller versions might be suitable for the executive mission, though this premise and its associated economics need further study.

The humanitarian misssion operational parameters were found to be compatible with the advanced V/STOL concepts; but it is doubtful that civil operators could dedicate these aircraft to only this kind of mission in view of the small and infrequent demand. Civil operators, employing advanced V/STOL aircraft for other primary missions, could, on the other hand, support humanitarian missions under certain conditions.

The study results conclude that the lift fan aircraft and the tilt rotor promise to be very productive vehicles (load capacity times speed), that can generally perform a specific task in considerably less time than contemporary aircraft.

It was found that these advanced vehicles are economically attractive at utilizations of approximately 800 hours per year or more. Because of the high productivity of these advanced concepts, a significantly larger demand for service per aircraft is required than for the contemporary aircraft used for comparison. Where the demand and mission requirements justify the use of the advanced concepts, their higher hourly costs are offset by their high

productivity, making them an economically attractive investment.

2. INTRODUCTION

Historically the introduction of helicopters for civil use has followed their application for military missions. At this point, some 30 years after the introduction of a practical helicopter and its purchase by the military, helicopter manufacturers are just now beginning to market helicopters developed specifically to meet civil mission requirements. During the past decade, studies of civil V/STOL markets have been conducted by the government and industry, particularly in the area of short haul transportation (e.g., The Northwest Corridor Study), but the market uncertainty and the high cost of development have resulted only in "paper" aircraft to date.

The military, on the other hand, are proceeding with advanced forms of V/STOL aircraft. NASA and the military services have test flown prototype V/STOL aircraft ranging from the Ryan XV5-A lift fan, to the Bell XV-3 tilt rotor, to the LTV XC-142 tilt wing. The British Hawker Siddeley Harrier, a VTOL lift engine fighter, is in service with both the RAF and the U.S. Marine Corps. The U.S. Air Force has development contracts for the YC-14 and YC-15, two large STOL prototype transports, and the U.S. Navy is currently developing the VTOL XFV-12. The attractiveness of these and other V/STOL's have sustained this development effort and now new designs and advanced technology are providing promise of even better performance.

It appears that civil operators desiring advanced V/STOL aircraft must still await military development and adapt military V/STOL aircraft to civil uses. In studies conducted by McDonnell Aircraft Company (Reference 2) and Boeing Vertol Company (Reference 4), advanced V/STOL concepts with 5000 lbs. payload capacity were analyzed for military type missions. These advanced concepts included the lift fan aircraft, the tilt rotor aircraft, and an advanced helicopter. This report examines in some detail the extent these advanced concepts, of the size and performance specified, can enhance the civil utility missions currently being performed by conventional aircraft or other forms of transportation.

The appendices to this report are found in a separate volume which contains additional details regarding the definition of the three advanced concepts studied plus a detailed description of the computer programs and the mathematical development of the analysis equations.

3. STUDY APPROACH

A. GENERAL

The approach to mission analysis was conducted as a multistep process comprising the following:

1. The production of consistent aircraft definitions;
2. The survey of potential missions and the development of mission descriptions;
3. The merging of aircraft and mission information to calculate the aircraft mission performance parameters;
4. Finally, the analysis of performance data to determine any aircraft preference based on established measures of performance.

Mission analysis tools were developed to provide the necessary flexibility to model a diversity of missions and a number of aircraft, and to analyze performance in accomplishment of the missions. Since analysis of a given aircraft in mission performance was repeated a significant number of times to permit parametric variation, special computer programs were utilized. Computational facilities at The Aerospace Corporation include the capability to perform batch processing, or, by use of remote terminals, to operate in an interactive mode with the computer. The analysis programs were written in APL (1)[1], a concise and powerful programming language designed for the IBM System/360. This programming permits a high degree of interaction between the operator and the computer. The interactive mode was selected since it provided the capability to make analysis runs, observe results, and change parameters as desired to obtain modified results. This quick reaction also provided a capability to rapidly modify the computer programs to meet the demands of analysis or input/output requirements.

Figure 3-1 is a general overview of the analysis method in functional flow showing those functions that were performed manually and those

1 References listed in this report are noted by parenthetical numerals, footnotes by superscript numerals.

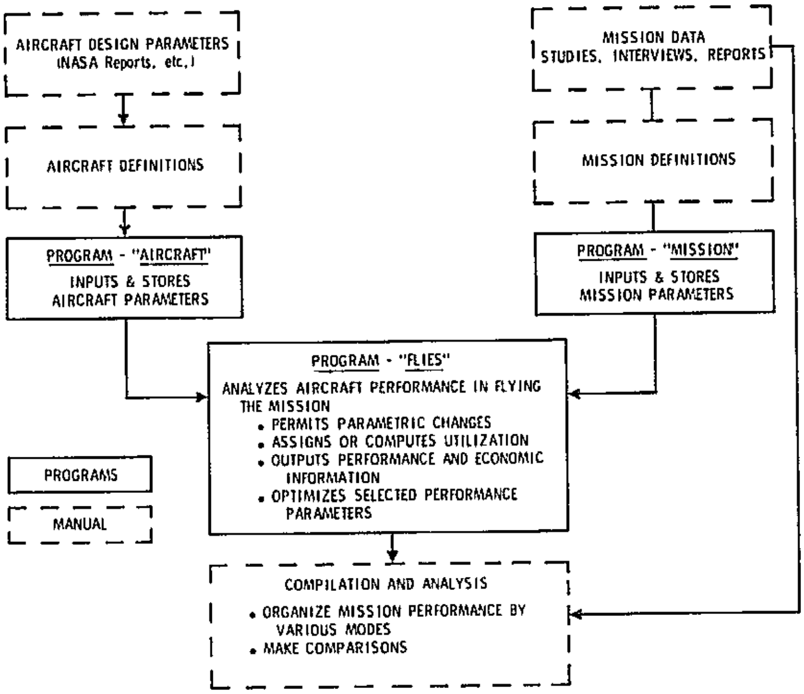

Figure 3-1. Overview of Functional Flow of V/STOL Mission Analysis

accomplished by the computer. The following paragraphs detail the functions illustrated.

B. AIRCRAFT DEFINITION

The aircraft definition function was manually performed and provided a standard description of all aircraft used in the analyses. It accepted data inputs obtained from design reports, operating manuals, sales brochures, etc., and reduced this conglomeration of inputs to standard format. It not only produced standard parameters, but also permitted the development of parameters using consistent ground rules or guidelines. This is extremely important since data available on a variety of aircraft may lack consistency in its scope of presentation and/or method of development. Finally, this function placed the data in the data base available for computer analysis.

Section 4 describes the details of each aircraft definition, therefore, this section concentrates on the computer program AIRCRAFT.

AIRCRAFT is an interactive program which leads the operator by means of questions through the insertion of all the necessary aircraft parameters into the data base. Nominal and alternative parameters are designated to permit flexibility in selecting the flight mode for the aircraft. Many of the aircraft parameters, in particular, speeds and fuel consumption rates, may be reasonably represented as linear functions of aircraft altitude and weight. In some cases more than one linear function is necessary to cover wide aircraft operating ranges. This program provides the flexibility to use special or alternate linear functions in these cases.

The advanced concept aircraft were defined in terms of their performance to the detail required by the analyses by means of practical ground rules, assumptions, and definition formats. Definitions of the advanced aircraft were derived from reports and other technical data provided by NASA. Because the data required for the different aircraft were not necessarily consistent in level of detail and form, they required considerable manipulation before they were useable in the general form required by the analysis programs.

Contemporary helicopters and airplanes used for comparison purposes were also defined to the same format as the advanced aircraft. The basic data used to derive the aircraft definitions were obtained from manufacturer's technical and sales data, pilots handbooks, and interviews with operators.

Mission analysis program development revealed that the integrations necessary in problem solving were facilitated if the aircraft performance was expressed as coefficients of linear expressions. In this way, all integrations may be completed in closed form, reducing significantly the complexity of the programming tasks.

Analysis of a contemporary helicopter using linearized data applied to a test mission gave performance results which varied approximately three to four percent from the performance contained in the operations handbook. This relatively small error verified the desirability of using the linear description rather than attempting questionable improvement in accuracy at the cost of considerable programming complexity.

The linear performance parameters include the various speeds, rates of climb, and fuel flow rates. The general expression takes the following form:

$$\text{Function} = K_1 + K_2 \times \text{altitude (ft)} + K_3 \times \text{weight (lbs)}^1$$

In this form, cruise speeds generally yield positive values for K_2 and K_3, rates of climb yield negative values for K_2 and K_3, and fuel flow rates yield negative values for K_2.

Figure 3-2 is an example of the development of a linear equation from actual data. In this case the climb fuel flow for the lift fan aircraft is shown. The variation in the fuel flow with altitude and weight are shown by the family of dashed curves. Straight line approximations for these curves are depicted by the solid lines. The linear function $\overset{o}{W}_{fcl}$, is shown

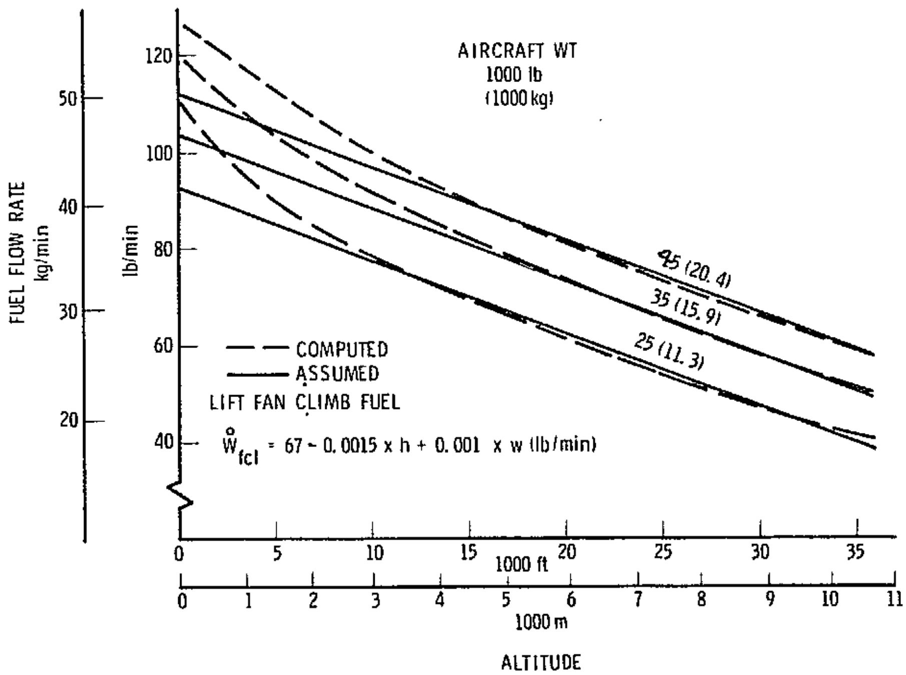

Figure 3-2. Example of Linear Representation of Performance Parameters

[1] All computations are performed in English units; therefore, all computer data bases, input and output formats are in English units only.

with its three coefficients. Not all parameters examined are as compatible to linear representation as the example shown. However, knowledge of how the aircraft is generally employed (e. g., low altitude and/or heavy weight) permits the linear approximations to be biased to obtain better representation in that portion of the performance region most often used. (The analysis tools have the flexibility to accept alternate values where it is desirable to have two separate definitions, thus permitting better curve matching.)[1] For example, in Figure 3-2 at high altitude there is less error in the linear representation for the heavy aircraft than for the lighter one. The curves were biased to provide more accuracy for the heavy weight aircraft at altitude, since the time to climb at a high altitude is greater for the heavier aircraft, thus making it more sensitive to error in total fuel used than for the lighter one.

Table 3-1 is a complete listing of all the parameters used to describe an aircraft in this study. In all, there are 75 entries required to completely describe an aircraft according to the specification of this table.

C. MISSION DEFINITION

Missions appropriate for the three advanced V/STOL aircraft were selected from a list of possible missions.[2] Those judged grossly inappropriate in the initial screening were discarded, the others were examined in more detail. For each mission type examined, data was obtained from various sources to describe the mission and to indicate its demand. (In the case of the humanitarian mission, timely statistical information was not available; thereby requiring this mission to be synthesized.)

Detailed mission descriptions are included in Section 5 preceding each mission analyses. These descriptions provide a general discussion of the purpose and manner in which the missions are performed. Also

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1 Details relating to any specific problems relative to linearization are discussed in Volume II of this report.

2 See Table 5-1.

Table 3-1 Aircraft Definition Parameters

PARAMETERS	REMARKS (Parameter composition, use, etc. See Table 4-2 for examples.)
Maximum Takeoff Weight	VTOL weight (constant)
Alternate Takeoff Weight	STOL weight, or external load overweight (constant)
Operating Weight Empty	Constant
Maximum Passenger Capacity	Constant
Maximum Fuel Capacity	Constant
Nominal Climb Speed	a
Alternate Cruise Speed	a, b
Nominal Cruise Speed	a
Alternate Cruise Speed	a, b - or to provide a 2-cruise-speed capability
Loiter Speed	a - also used for holding and search
Nominal Rate of Climb	a
Alternate Rate of Climb	a, b
Nominal Rate of Descent	Constant
Alternate Rate of Descent	Constant
Idle and Taxi Fuel Rate	Constant plus Altitude Coefficient
Nominal Takeoff Fuel Rate	a
Alternate Takeoff Fuel Rate	a
Nominal Cruise Fuel Rate	a

a Constant plus altitude and weight coefficients

b Used for aircraft with external load capability

Table 3-1 Aircraft Definition Parameters (Cont'd)

PARAMETER	REMARKS
Alternate Cruise Fuel Rate	a, b - or to provide a 2-cruise-speed capability
Hover Fuel Rate	a
Loiter Fuel Rate	a - also used for search
New Cost of Aircraft	Constant
Cost of Auxiliary Equipment	Extra equipment required, but not in new cost
Insurance Premium	Percent of value per year
Salary Crew	Dollars per year - each
Maintenance Labor	Hours per flight hour
Maintenance Parts	Dollars per flight hour (includes reserves)
Nominal Flight Crew	Number
Type of Fuel	Aviation Gasoline or Jet Fuel
Cost of Fuel	Dollars per Gallon
Cost of Lubricants	Dollars per Hour
Special Cruise Speed	c
Critical Altitude	Altitude at which special coefficients apply
Special Cruise Fuel Rate	c
Service Ceiling	Constant plus weight coefficient

a Constant plus altitude and weight coefficients

b Used for aircraft with external load capability

c Three coefficients for high altitude, long range cruise to correct for linearization error

indicated are those areas of the world in which the missions are generally flown. Each mission was quantified in terms of the typical parameters used in the analysis to evaluate the aircraft's mission performance. The parameters were varied parametrically to ascertain each aircraft's general suitability to the mission.

Relative mission performance was measured by comparing the aircraft operational and economic suitability for each mission against known standards of performance. The resulting performance measurements included range versus payload curves and time to complete the mission for each mission profile. The economic measures are generally stated in terms of costs per passenger unit distance, cargo unit weight - distance, or costs per hour expressed as a function of annual flying hours.

As with aircraft definition, the objective of the mission definition is the determination and standardization of the parameters used to describe the mission. The specifics of the various missions are covered in Section 5; therefore, only the general mission format and guidelines used in mission definitions are discussed in this section.

Missions were effectively described by dividing them into standard segments. Table 3-2 lists the 18 segments used in this study with the parameters employed to describe each segment.

The computer program MISSION, like the program AIRCRAFT previously described, is interactive and leads the operator by questions through the insertion of mission definition parameters.[1] This program is initiated by calling the program and indicating by segment number the order of segments defining the mission.

Some of the times assigned were arbitrarily chosen; however, they were selected judiciously and assigned consistently, and are fairly representative of actual situations. Therefore, they do not penalize any concept without justification. For example, it was generally assumed that VTOL

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1 See Volume II for additional details of program operation.

Table 3-2 Mission Description Segments and Parameters

SEGMENT NO.	SEGMENT NAME	PARAMETERS*
1	Load	Time to load (min) Passengers loaded (no.) Internal cargo loaded (lbs) External cargo loaded (lbs)
2	Warm-up	Time to warm up (min.)
3	Taxi	Time to taxi (min.)
4	Conventional Takeoff	Time to take off (min.) Elevation of takeoff (ft)
5	Short Takeoff	Time to take off (min.) Elevation of takeoff (ft)
6	Vertical Takeoff	Time to take off (min) Elevation of takeoff (ft)
7	En Route	Distance (nm) Maximum altitude (ft) Minimum Altitude (ft)
8	Descent	Distance to descend (nm)
9	Conventional Landing	Time to land (min) Elevation of Landing (ft)
10	Short Landing	Time to land (min.) Elevation of landing (ft)
11	Vertical Landing	Time to land (min.) Elevation of landing (ft)
12	Unload	Time to unload (min) Passengers unloaded (no.) Internal cargo unloaded (lbs) External cargo unloaded (lbs)

* Some parameters may be a range of numbers; i.e., passengers = 5-15.

Table 3-2 Mission Description Segments and Parameters (Cont'd)

SEGMENT NO.	SEGMENT NAME	PARAMETERS*
13	Refuel	Time to refuel (min.) Fuel to maximum capacity (yes/no) Amount (min.) if above is no
14	Loiter	Time to loiter (min.) Loiter altitude (ft)
15	Hover	Time to hover (min.) Hover altitude (ft)
16	Search	Time to search (min.) Search Altitude (ft)
17	Standby	Time (min.) (Time aircraft is operational, but not flying between missions)
18	Inactive	Time (min.) (Time aircraft is out of service and not available for mission flight, e.g., mission must be flown in daylight - 12 hours)
	Other Parameters	Number of hours per day available for this mission (e.g., mission must be flown in daylight - 12 hours)
		Number of extra crew members required, e.g., observer, winch operator, navigator, scanners, radio operator, etc.
		Mission Related Costs; significant costs attributed specifically to this mission and which are not included in the operating costs of an aircraft unless assigned the mission ($/hr).

* Some parameters may be a range of numbers; i.e., passengers = 5-15.

aircraft do not have a taxi segment in their mission, while CTOL or STOL aircraft are required to taxi. Even then, it was assumed that CTOL taxi is greater than STOL. The exact amount of this difference may depend on the type of airport at which the mission originates, i.e., a major air terminal or a small general aviation airport. Thus, these and other parameters were quantitatively assigned appropriate values consistent with the mission condition.

Takeoff generally was assigned a time duration of one minute and primarily influences the takeoff fuel requirements. No distance is associated with this segment; however, the takeoff altitude must be specified.

The en route segment includes climb, descent and level cruise. This segment describes a nominal distance and any altitude restrictions en route. The minimum altitude parameter relates to any current operating practices or possible geographic constraints that would impact the mission in a particular portion of the world. Maximum altitude is generally set at the greatest of the service ceilings of all the aircraft expected to fly the mission, unless there is a mission requirement to stay below a designated altitude - a visual search, for example.

If, during cruise or descent, it is desired to perform a loiter, hover, or search before landing, this may readily be accomplished by specifying the altitude at which this will occur, and the distance remaining to the landing site after the loiter, or search is performed. In this case, a special descent segment is employed, not to be confused with the descent that normally takes place in the en route segment. The purpose of this special descent segment is to get the aircraft to the elevation of the landing area. The descent segment is not needed if the loiter, hover, or search occur at the same elevation as the landing site. The distance parameter in this special segment determines where the loiter, search or hover occurs relative to the landing site.

Times in the load, warm-up, taxi, unload, standby, and refuel segments are used principally to account for the nonproductive, or

overhead, times charged to the mission. These times do not generally reflect significant fuel useage, or even contribute significantly to maintenance costs; however, they influence how many missions may be flown in a given time period, and affect the total aircraft productivity in terms of missions per unit time.

The refuel segment performs another function beside that of accounting for time; it permits a mission to be described which includes necessary refueling stops, and designates the amount of refueling.

The hover segment is used to describe a principal part of a mission including hover not incidental to takeoff or landing. The segment description includes the altitude at which hover is conducted, and the amount of time involved.

Loiter is used to account for holding time and fuel, and does not contribute to covering any distance which may be specified in the en route segment. Loiter altitude and time are specified.

The search segment distance covered is not generally applied to the en route distance although the distance is calculated and made available as an informational output. Likewise, computations such as passenger or ton miles are not computed for this segment. Inputs required are search altitude and elapsed time.

The inactive segment permits accounting for time blocks when the aircraft is not available for operations, such as maintenance. Its principal effect is on annual utilization.

The following additional general mission parameters are essential to the program and are assigned values in the description of the missions:

1. Aircraft fueling indicates whether or not the aircraft is to be fully serviced at the start of the mission, or whether a specified number of minutes of fuel should be loaded.
2. Average daily hours available for operations establishes the maximum daily use of the aircraft for the mission and may be used in lieu of a specified standby element.

3. Hazardous missions are identified to allow for the possibility of extra insurance premium or crew bonuses. (Although available, this parameter was not used in this study.)

4. Extra crewmen required are indicated to adjust costs and aircraft loading, if extra crew are required.

5. The fuel reserve (in minutes) is used to compute any extra fuel load required, and to input minimum fuel constraints.

6. Mission related costs not otherwise accounted for are identified. This feature permits any major items to be included in the economic analysis which are not handled directly in the computation of operating costs.

The mission definition permits the repetition of a segment, or series of segments, any number of times providing no parametric values are changed. This option is available by identifying the segments to be repeated and number of repeat cycles, without the need to redefine the parameters individually.

D. AIRCRAFT AND MISSION ANALYSIS

The computer program FLIES provides for the rapid merging and analysis of the data base describing an aircraft with that describing a mission. The complete description of this analysis program is relatively involved; therefore, the discussion here is limited to the functional highlights and leaves the technical detail to Volume II. Figure 3-3 summarizes the functions of FLIES in flow chart format.

The FLIES program is interactive and queries the operator during initialization to set desired values in the variable parameters. The analysis is initiated by identifying the aircraft and mission (by stating their names). Immediately thereafter the operator is requested to select one of four output options:

1. Complete output;
2. Detailed aircraft operational performance;
3. Detailed economic performance, or;
4. Summary

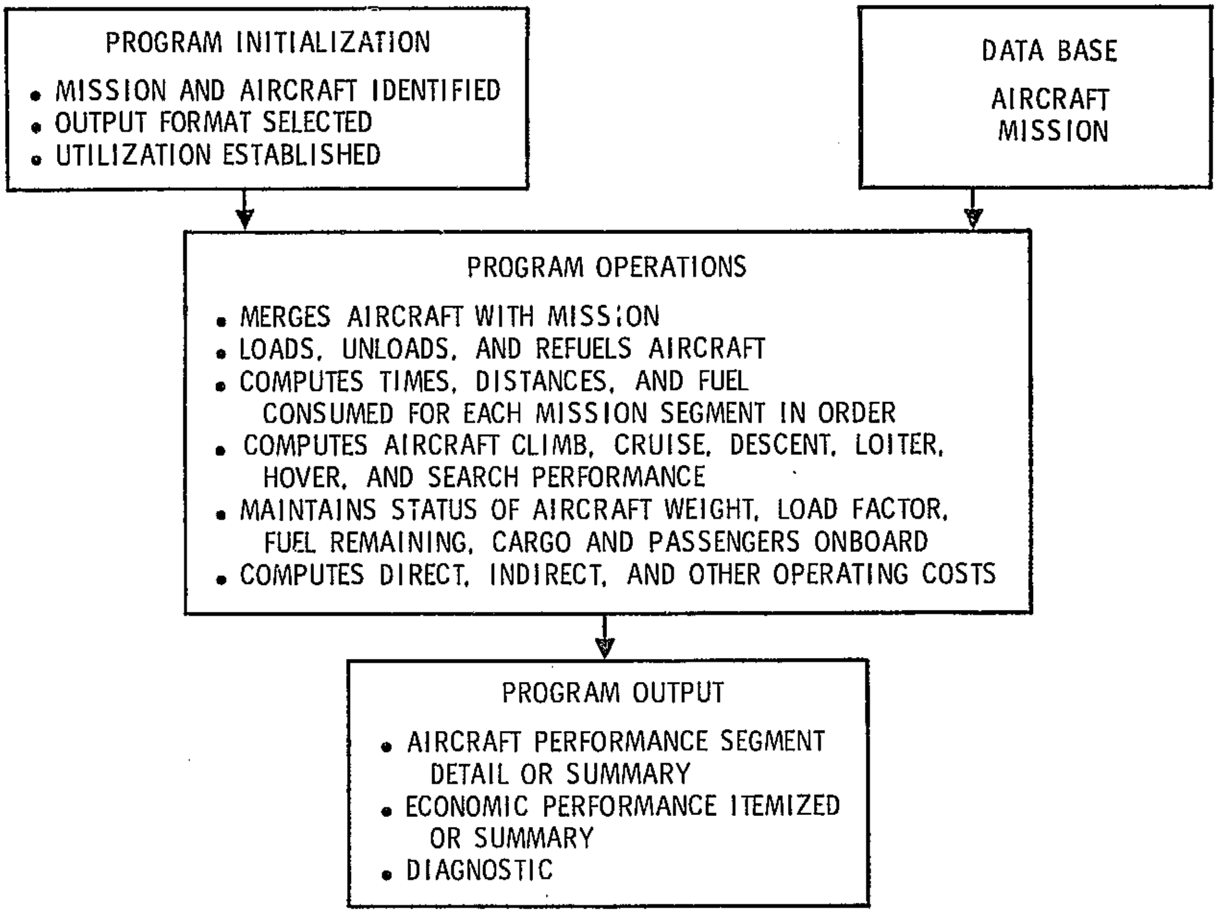

Figure 3-3. Summary of Mission Analysis Program FLIES

Table 3-3 is a typical output format showing the complete output (Option 1). The operational performance output (Option 2) includes the mission segment data, and the operational and economic summaries. The economic performance output (Option 3) includes the itemized economic data, plus the operational and economic summaries. The summary output (Option 4) contains only the summaries.

The operator may indicate utilization by entering either the number of flying hours per year or the number of missions per year.

Once the initialization is completed, the program begins to execute. Computing time is very short with almost all the elapsed time consumed in the printout.

The first action in the computation is the loading of the aircraft to meet the mission requirements. For this reason, the mission must be defined starting with a load segment. Each segment is solved in order. Segment results are printed if the total, or performance option is selected. The printout is the only record of the analysis, since the results are not stored for future retrieval.

In the en route segment, the distance may be too short to permit the aircraft to climb to the lesser of the aircraft ceiling or the specified altitude; in this event, a flight profile consisting of a climb and descent leg is computed. Climb and descent legs are iterated until climb and descent distances total the specified en route segment distance. If the specified minimum mission altitude is not reached, the computation stops and a descriptive diagnostic message is output. Where the en route distance is great enough to allow the aircraft to reach the designated maximum altitude, or the aircraft ceiling, the climb, cruise and descent legs are all computed in an appropriate fashion.

Normal descent from cruising to landing altitude is computed based on specified descent rates; therefore, the point at which descent starts during the en route segment is established from rate of descent, air speed, and altitude differential.

If a search, loiter, or hover segment follows an en route segment, the descent from cruise altitude will be calculated on any specified differences between the cruise and search (or loiter, or hover) altitude using the specified descent rate. Descent is initiated to arrive at the search (loiter, or hover) altitude and distance from the landing site as specified by the descent segment. It should be understood that the total distance flown is controlled by the en route segment and that the distance specified in the descent segment is not additive. If a landing occurs following search, loiter, or hover, and a descent is required, the descent rate is determined by the altitude differential, the ground distance remaining to travel, and the air speed coefficients.

Fuel reserves are checked after each segment is completed to determine if sufficient fuel remains to meet mission reserve requirements. Fuel reserve estimates are made assuming a flight altitude of 10,000 feet at either normal or alternate cruising conditions.[1] The 10,000 foot altitude was assumed to provide reasonably conservative reserve estimates. The use of nominal or alternate cruise speed and fuel consumption permits the operator to select the more appropriate fuel mode. For example, for an aircraft cruising at maximum cruise speed, it is generally more realistic to compute reserves based on maximum range conditions rather than the high speed cruise. Thus, the program gives the analyst the option of using the fuel parameters for either maximum cruise speed or maximum range in setting up the mission.

For most missions, the cruise portion of the en route segment accounts for most of the distance traveled, the elapsed times, and the fuel consumed in the overall mission. For this reason, special flexibility is designed into the program for aircraft cruise to provide reasonably correct performance results over the widest operating ranges expected. This is accomplished by allowing the use of alternative coefficients in the cruise performance equations for a particular aircraft which are specifically tailored to the cruise altitude operating ranges. In effect, one or two

[1] Specified in the aircraft description.

sets of cruise performance coefficients are used below a specified altitude, and an alternative set is used above the specified altitude at the option of the user.

The performance output shown in the example in Table 3-3 (Part I) lists the segments by name which comprise the example mission. The en route segment is divided into its three components; climb, cruise, and descent. The distance contribution of each segment (or subsegment) is shown, along with the elapsed time and fuel consumed for each. Cargo and passengers are summarized at each point in the mission and reflect changes at load or unload segments as they occur. The aircraft weight is shown at the end of each segment and accounts for fuel consumed and changes in cargo and/or passengers. The load factor is computed as the ratio of the weight carried to the weight which could be carried considering the fuel loaded (subject to the ability to physically interchange fuel and cargo or passengers). In the example show (Table 3-3), if only 13,559 pounds of fuel had been loaded (reduced by 5000 pounds), the load factor would have been reduced to 0.55 with the 6070 pound load.

The detailed performance output is followed by a summary which totals the distance, elapsed time, and fuel used columns, and presents a distance weighted average for the load factor. The performance summary shows the "engine on" time as "aircraft utilization - hrs/mission." The maximum number of missions per year (730) reflects the number of integer missions which can be flown in the daily hours available (specified as 16 hrs in this case) times 365. The actual number of missions (190) reflects the integer number of missions per year considering the specified annual utilization (1000 hrs/year). Comparison of these two numbers shows that the 1000 hrs per year utilization is the major constraint for this example. The mission flight efficiency can be judged by comparing the payload ton miles available to those actually flown in the mission.

The economic performance shows costs compiled and displayed on an hourly or mission basis. Further, the costs are divided into three

Table 3-3. Example of Total Output Format

(Part I)

MODE COMPLETED	ELAPSED DISTANCE N.MI.	ELAPSED TIME HRS.	FUEL USED LBS.	FUEL REMAINING LBS.	CARGO ONBOARD LBS.	PASSENGERS ONBOARD NO.	AIRCRAFT WEIGHT LBS.	LOAD FACTOR -
LOAD	.0	.17	0	18559	6070	0	45000×	1.00
WARMUP	.0	.02	152	18407	6070	0	44848×	1.00
SHORT TAKEOFF	.0	.02	254	18153	6070	0	44594×	1.00
ENROUTE	1000.0	2.50	9485	8669	6070	0	35110×	1.00
CLIMB(36000 FT. MAX)	(157.1)	(.53)	(2288)					
CRUISE	(572.9)	(1.36)	(4728)					
DESCENT	(270.0)	(.60)	(2468)					
LOITER	.0	.33	998	7671	6070	0	34112×	1.00
VERTICAL LAND	.0	.02	205	7466	6070	0	33907×	1.00

×=ALTERNATE AIRCRAFT CONFIGURATION

[a]TOTAL MISSION	ELAPSED DISTANCE N.MI.	ELAPSED TIME HRS.	FUEL USED LBS.	LOAD FACTOR -
	1000.0	3.06	11093	1.00

[a]

AIRCRAFT UTILIZATION HRS./MISSION	AIRCRAFT UTILIZATION HRS./YR.	MISSIONS PER YEAR MAXIMUM	MISSIONS PER YEAR ACTUAL	AVAILABLE PAYLOAD TON MILES	MISSION PAYLOAD TON MILES
2.89	1000	1825	346	3035	3035

[a] Summary data outputs

Table 3-3. Example of Total Output Format
(Part II)

DIRECT OPERATING COSTS	PER MISSION	PER FLIGHT HOUR
FLIGHT CREW	173.42	60.00
FUEL+OIL	830.73	287.42
INSURANCE	361.26	124.99
MAINTENANCE,LABOR	.00	.00
MAINTENANCE,PARTS	867.09	300.00
DEPRECIATION	456.95	158.10
TOTAL DOC	2689.45	930.51
MISSION RELATED COSTS		
TOTAL MRC	.00	.00
OTHER COSTS		
INTEREST	174.18	60.26
TOTAL OC	174.18	60.26
[a] TOTAL COSTS	PER MISSION	PER FLIGHT HOUR
	2863.63	990.78
[a] DOC/MISSION PAYLOAD TON MILE	.89	

[a] Summary Data Outputs

Table 3-4. Example of Summary Output Format

TOTAL MISSION	ELAPSED DISTANCE N.MI.	ELAPSED TIME HRS.	FUEL USED LBS.	LOAD FACTOR -
	1000.0	3.06	11093	1.00

AIRCRAFT UTILIZATION HRS./MISSION	HRS./YR.	MISSIONS PER YEAR MAXIMUM	ACTUAL	AVAILABLE PAYLOAD TON MILES	MISSION PAYLOAD TON MILES
2.89	1000	1825	346	3035	3035

TOTAL COSTS	PER MISSION	PER FLIGHT HOUR
	2863.63	990.78
DOC/MISSION PAYLOAD TON MILE	.89	

Table 3-5. Program FLIES Diagnostic Condition and Message Output

Maximum Passenger Capacity Exceeded by (   )*
Takeoff Weight Limitation Exceeded by (   ) Lbs
Fuel Onboard Insufficient For (   ) Minute Reserve
    by (   ) Min
Ran Out of Gas By (   ) Lbs
Unloaded Too Many Passengers By (   )
Unloaded Too Much Cargo By (   ) Lbs
Maximum Fuel Capacity Exceeded By (   ) Lbs
Maximum Cargo Exceeded By (   ) Lbs
Minimum Altitude Not Attained By (   ) Ft

---

*(   ) appropriate value inserted

categories, direct operating costs (DOC), mission related costs, and other costs. Costs that are defined on an annual basis are amortized over the indicated annual utilization (1000 hrs) or annual number of missions (depending on the column concerned). Costs defined in other terms are computed and distributed appropriate to the two columns shown. Finally, the costs data are summarized by totaling the two columns and computing a value for DOC per mission payload ton mile.

If the operational performance output is suppressed (i.e., selection of economic or summary output options), then summary statements for operations performance are printed out. A typical summary output is shown in Table 3-4.

Whenever the program computes a condition which violates critical aircraft or mission parameters, the program halts and the operator is informed of the violation by means of a diagnostic message. The condition associated with each message is self-evident as shown in Table 3-5. When such a message is displayed, the operator must make a change to appropriate aircraft or mission parameters (if practical), and re-initiate the run in order to obtain a valid result.

By performing repeated analysis runs and changing the values of the critical parameters, results are accumulated for subsequent manual resolution and analysis. The manual analysis may well result in the need to answer additional questions requiring more computer runs to vary parameters in different combinations or over different ranges.

E. THE ECONOMIC MODEL

The economic model is described here since it is combined in the aircraft description, the mission description, and the analysis program FLIES. Reference to the aircraft definition parameters listed in Table 3-1 shows that nine parameters relate directly to the economic model; these include such items as the new cost of the aircraft, costs of maintenance, crew salary, etc. It may be seen in Table 3-2 (list of the mission

parameters), that some of these, too, have direct economic implication, such as numbers of extra crew members and mission related costs.

From the discussion of the computer program FLIES it should be clear that the derived aircraft and mission parameters are used to compute the costs associated with mission operations. In addition to performing calculations to arrive at mission fuel costs, FLIES contains an economic model to calculate depreciation, insurance premium, interest costs on aircraft financing, etc.

The economic model used for the V/STOL studies considers all the principal costs associated with the operation of a given aircraft over a typical year in the performance of a given mission. The model is a practical representation of operating costs. However, it should be made clear that the development of costs can be quite subjective, and authoritative data are sometimes difficult to obtain on operating aircraft. Cost estimation on aircraft not yet produced becomes even more subject to uncertainty.

Cost definition data fall into two classifications; those related to contemporary aircraft, and those related to the advanced concepts. It may be thought that information relating to contemporary aircraft would be simple to acquire. Such is not always the case. Some operators feel that manufacturer's maintenance figures may be on the optimistic side; on the other hand, these operators may consider their cost factors proprietary and are reluctant to release them. Therefore, this study relied principally on manufacturers' published costs as modified by judgments obtained from operators flying the machines.

The direct operating cost is generally considered to include both fixed and hourly components. The fixed portions of the cost are those that accrue regardless of flying hours and include annual depreciation, insurance premiums, and flight crew salaries.

The hourly cost components can be assigned to an hour's operation of the aircraft and include such items as fuel, lubricants, reserves for

airframe and engine overhauls, scheduled and nonscheduled maintenance, parts replacement, and labor

A major contributor to the fixed cost is the value of the aircraft. The rate of depreciation determines that portion of this value "consumed" during a year's operation. Many economic studies use depreciation schemes derived from accounting practices applicable to income tax returns. Tax-type depreciation is not believed justified in this study and complicates the economic modeling without good cause.

Information from airframe manufacturers indicates that the useful life of a properly maintained helicopter is of the order of twenty or more years. At the end of that time it will still have some salvage value. This study assumed that salvage value was 15 percent of new cost. It is also assumed that an operator will keep the machine for a long period so that his expenses are averaged over a reasonably large number of years. In this way, he is exposed to most, if not all, of the overhaul and replacement cycles suggested by the manufacturer, or required by the FAA. This permits the use of maintenance reserve funds recommended by the manufacturer as a reasonably good (if sometimes optimistic) indicator of the costs of maintenance. The annual depreciation used is the arithmetic average for one year as the aircraft depreciates from its new to salvage value over a twenty-year period. It is reasonable to believe that an operator will not own an aircraft for its full twenty-year life span. However, if he sells it earlier, any reserves accumulated and already allocated to maintenance, but unspent for repairs represent money on hand, an additional value above the sales price of the machine. Should he sell the machine just after making needed repairs, the price received will generally be higher than in the first case; in the end, differences tend to balance out. It makes the analysis less complex to assume one owner, straight line depreciation and full expenditure of mainteance reserves rather than unduly complicating the model. The results of the analyses show the costs of performing a mission by

using a machine dedicated for its lifetime to the mission. Since this establishes a standard of measure, it should not unreasonably penalize any concept, current or future.

The purchase prices of the aircraft were determined by two different means depending on whether the aircraft were contemporary or advanced. For the contemporary aircraft, the price information available in January 1975 was used. For the advanced concepts, several assumptions were made.

The first, and most significant assumption, provided that the aircraft is developed and procured as a military item, and that the basic research and development costs of airframe, dynamic system, and engines are borne by the military.

The second assumption concerns the costs of modification and certification for civil use. It was assumed that some nominal modifications are made in design and production tooling. Thus a prototype civil test article is built and necessary certification tests are performed. These costs were prorated over an assumed 100 civil production units.

Basic cost data were derived from the contractor's reports where available. Where these data were not provided, costs were developed using industry rules of thumb based on weights of major components. The details relative to the cost estimation of each aircraft are discussed with the aircraft's definition.

Another major fixed expense is the annual insurance premium. In practice, the insurance premium is based on the value of the machine in any given year. Here depreciation rate given by an arithmetic average yields some unrealistic results. Therefore, study results of nominal depreciation curves for two medium lift helicopters and two business jets were used.

Data were only available for six to eight years, these were regressed and extrapolated to twenty years. The mean value of the aircraft over the

twenty-year period when depreciated to 15 percent of its new value was calculated to be 42 percent of its new value. The insurance premiums were calculated on this mean value for the life of the aircraft. Thus, the model does not differentiate between the insurance premium of a 10-year old contemporary aircraft and a new advanced concept, providing that their initial costs are the same. By assuming the operator owns the aircraft for its entire lifetime, complications are avoided.

Insurance underwriters advised that there is little indication today that one use of helicopters is favored over another. That is, one mission is not rated at a higher accident potential than another. This is partially due to rating the operator's past experience in broad-mission categories and not on a mission-by-mission basis. Also, with so few machines operating, one accident can impact all operators to some extent. The larger fleet operators get the best rates available because their risks are spread over a large fleet; plus, they generally have demonstrated the ability to select, train, and discipline their air and ground crews so that losses are less likely. Operators of individual machines do not generally meet these preferred insurance risk conditions.

Expert industry opinion on helicopter insurance premium rates indicated that the market is extremely variable with time. Several causal factors are cited; operator's loss experience, fleet size, and the number of underwriters in the market. The latter is of major significance. Currently with a large number of underwriters in the market, rates are relatively low - of the order of four to six percent of the helicopter's replacement value. Such conditions in the past have caused underwriters to lose money and leave the market with the result that rates have risen to 10 and 12 percent. Those companies that stay in the market on the long term can be expected to set premiums near eight to ten percent. For an overall average for the next 10 years, eight percent appears to be a reasonable assumption. Conservatism might dictate the use of higher rates initially for newer technology concepts which have little operational data to establish

more favorable rates. Therefore, at their introduction, the lift fan and tilt rotor aircraft might be expected to pay higher average premiums than the conventional helicopter, or the advanced helicopter design used in this study. However, these differences will tend to diminish with operational maturity, and for this study the average annual insurance premiums is assumed to be eight percent for all helicopters and advanced concepts.

While not necessarily thought of generally as an item of DOC, interest costs may be considered as another component of fixed costs. The cost of financing was standardized to be representative of the 1975 market. It was assumed that 80 percent of the original price is financed at eight percent interest, on a fully amortized, declining balance, and paid in eight equal payments. Under these conditions the total interest paid would be 32.4 percent of the original cost. This averages to 1.6 percent of the original cost per year for the 20-year useful life of the aircraft. Since the advanced concepts represent a large investment, it was felt that the cost associated with the investment should be charged against the use of the aircraft. It may be seen that the charge is listed as "other costs" in Table 3-3.

Hourly costs are principally those associated with fuel consumed, maintenance, and crew salaries. The analysis program determines the fuel consumption. Current, non-contract fuel prices were used to compute fuel costs. These costs run $.40 to $.90 per gallon for jet fuel and are higher than those paid by larger quantity buyers, such as the airlines, who pay from $.25 to $.35 per gallon, today. For this study, jet fuel cost was assumed at $.50 per gallon.

Maintenance costs are generally provided in the form of $/flight hour or a combination of labor hours/flight hour and $/flight hour for parts, etc. If the former is used it is an all inclusive number including parts, labor and reserves for engine and airframe overhauls. Generally, the larger operators can maintain their aircraft less expensively by performing their own overhaul of components. Data from one manufacturer

and one large fleet operator indicated that these savings are on the order of 10 to 20 percent, depending on the aircraft model. For this reason, it appeared that relatively large fleet operators would choose to do their own component overhaul instead of the more expensive component exchange. Their large fleets would make it reasonable to have the shop equipment and the skills to perform these overhauls at their main bases. However, the costs of the overhaul facilities are difficult to estimate; therefore, to more accurately reflect costs and to be consistent in this study, it was assumed that component overhaul is done by the manufacturer or by an outside contractor. Maintenance costs reflects these higher costs where they can be identified. Contacts with various operators indicated that where the costs for labor and facilities cannot be separated, a cost of $10/hour for labor is not unreasonable. This figure is substantiated by the current charges of upwards of $12 per hour at general aviation shops which do not require the extensive equipment required of these more sophisticated machines, but which include the shop profit. The number of hours required and the costs of parts and reserves are discussed for each aircraft in their definition.

One operator of a helicopter airline, also engaged in construction work, advised that heavy lift work reduces engine and transmission life up to 50 percent compared to the life expectancy on airline service. Where this is a factor additional costs may be input directly to the mission definition as "Mission Related Costs."

A survey of several companies employing a large number of helicopter pilots concluded that generally the more costly machines are flown by the more experienced and, therefore, the higher paid pilots. This reflects the operator's desire that his investment is in experienced hands. Also, it is generally agreed by the operators that it is not their practice to pay any premium to the pilots based on the type of machine or type of mission. Therefore, it was assumed that no premium, per se, is paid to pilots of the advanced concepts, but that they will be flown by the higher qualified, higher paid pilots.

Current salary of highly qualified pilots ranges from \$15,000 to \$20,000 per year, including fringe benefits, depending on the operator and his type of equipment. Crew salaries were assumed at \$20,000 per year for all aircraft examined, contemporary as well as advanced concepts.

Income tax savings can be favorable to businesses using helicopters; however, this is not considered in this study since there are too many variables which tend to complicate the picture and are of second order of importance in rating aircraft performance for a given mission.

Return on Investment (ROI) is not considered as a factor in the economic study. This is admittedly an important consideration and would be a cost item that would face a user contracting services from a fleet operator, although it may not be considered a distinct item to a company operating its own aircraft. However, a company operating its own aircraft would probably face extra expenses in the area of insurance, crew training, and maintenance, while the fleet operator with a relatively large number of aircraft would benefit from economies of scale. Thus, the differences tend to balance out.

To summarize, the economic model used is representative of a fleet operator owning a relatively large number of aircraft. Aircraft were assumed to be purchased new and retained for their entire useful life. Costs are representative of those before any profit can be made, and do not include a return on investment. Table 3-6 summarizes the details of the economic model by presenting the definitions and assumptions in the mathematical form used in the cost calculations. All costs are in 1975 dollars.

F. COMPILATION AND ANALYSIS

The objectives of this function are to organize the information obtained in the aircraft and mission analysis functions in a format to permit comparisons to be made between the advanced concepts and current modes. Considerable detail on the methods employed to accomplish these objectives is contained in the sections of this report describing the results;

Table 3-6. Economic Model Summary

Fixed Costs ($ per year)

$$\text{Depreciation} = \frac{\text{Cost New - Salvage Value}}{\text{20 Years}} = \frac{(1 - 0.15)\ \text{Cost New}}{\text{20 Years}}$$

$$= 0.0425\ \text{Cost New*}$$

$$\text{Insurance} = \text{Mean Value x P} = 0.42\ \text{Cost New x P*}$$

$$\text{Interest} = \frac{0.324\ \text{Cost New}}{\text{20 Years}} = 0.0162\ \text{Cost New*}$$

Crew = No. of Crew* x Annual Salary*

Hourly Costs ($ per hour)

Fuel: Jet = $0.50/gal

Avgas = 0.70/gal

Lubrication = $ L*/hr

Maintenance: Labor = $10/hr

Parts & Reserves = $R*/Flt hr

* Aircraft or mission definition item.

therefore, only a brief summary of the compilation and analysis is presented here.

Examples of the compilation procees include variations in number of missions, passengers and cargo carried, or cost per payload unit delivered as a function of mission distance for a given concept. Other parametric analyses possible include payload as a function of range, costs as a function of annual utilization, and sensitivity of mission costs to fly-away costs (or fuel consumption, or crew salary, etc.). The intent of the compilation is to distill the computer output into a form which permits ready and meaningful comparison between the various aircraft.

The information compiled on each aircraft is further combined to show the relative merit of the parameters of the various aircraft and their contemporary competitors, and to draw conclusions based on the comparisons. The emphasis on the various parameters is related to the mission; therefore, a mission-by-mission examination is required in the comparison process. The intent is to quantify, to the best degree possible, how much better one concept is over the others (including contempory modes).

4. AIRCRAFT DESCRIPTION

In this section, the advanced V/STOL and contemporary aircraft are described in detail. General configuration sketches of each aircraft are presented along with basic dimensional and operating information. The aircraft parameters are described in terms of their linear coefficients, and the rationale for assumptions pertinent to the development of aircraft and maintenance costs are provided. Those interested will find greater detail concerning the linear coefficients describing aircraft performance in Volume II of this report.

A. LIFT FAN AIRCRAFT DEFINITION

1. PERFORMANCE DATA

The lift fan design selected by NASA for this study is a McDonnell Aircraft Company (MCAIR) design prepared for the U. S. Navy. Aircraft design and performance data were obtained from reference (2) with additional data provided by NASA. The MCAIR design study was directed toward a number of Navy missions, one of which is the Vertical Onboard Delivery (VOD) mission. This mission provides logistic support to ships at sea. Since the fuselage of the VOD configuration is generally compatible with the civil utility applications, it was used for this study. Figure 4-1 shows the general configuration of the lift fan aircraft, while Table 4-1 contains dimensional and design data of interest.

The aircraft empty weight was only changed slightly to reflect two, rather than three, crewmen. It is felt that there is a balance between the military equipment removed and the new furnishing added to convert the interior for civil mission; therefore, no weight change was made for this purpose.

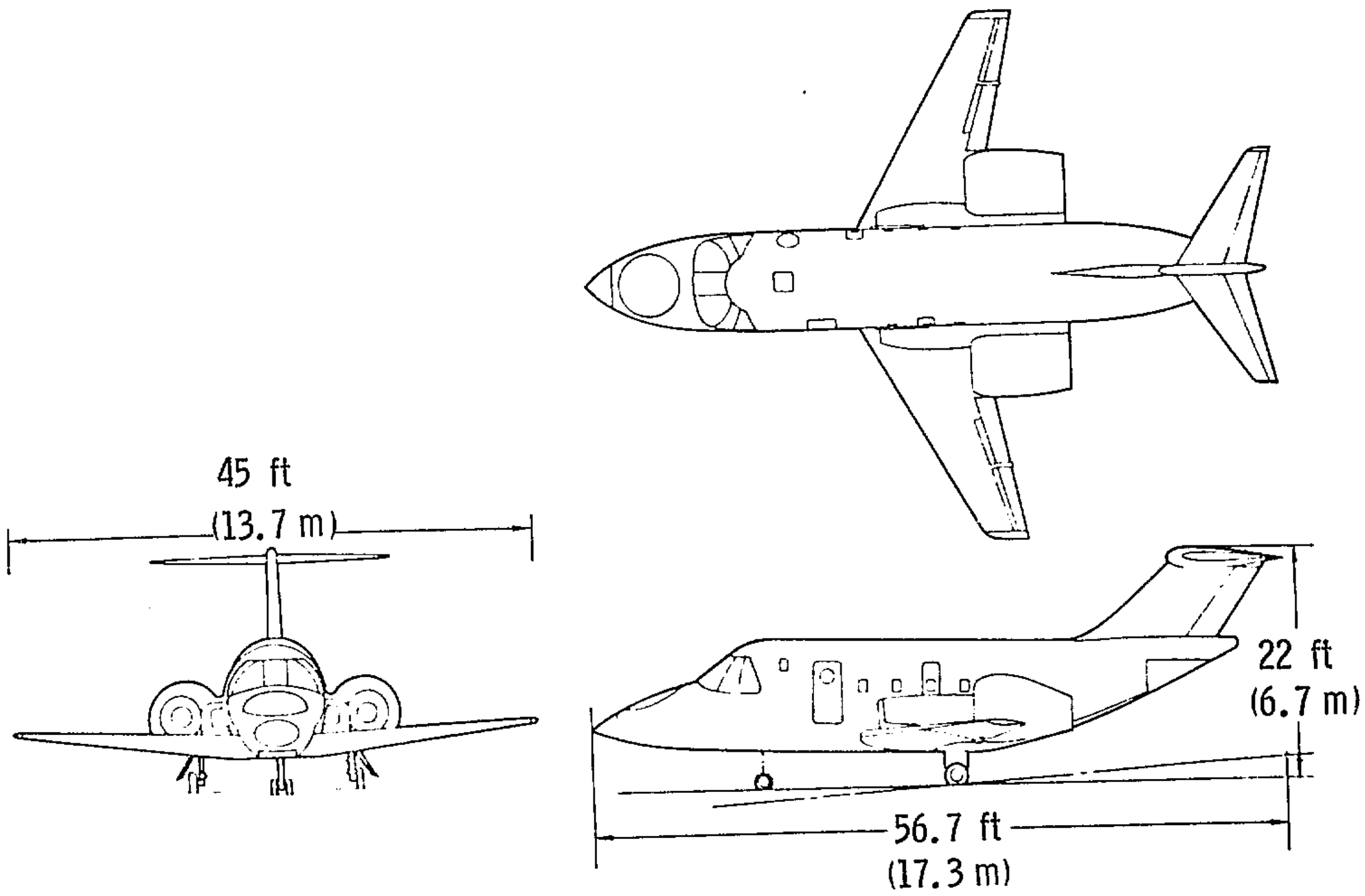

Figure 4-1. Lift Fan Aircraft General Configuration

Source: McDonnel Aircraft Company

Table 4-1. Lift Fan Aircraft Parametric Summary

Parameter	Value English	Value Metric
Takeoff Gross Weights[a]		
STO	45,000 lb	20,412 kg
VTO	35,850 lb	16,261 kg
Operating Weight Empty	19,846 lb	9,002 kg
Gas Generators - 3		
Airflow Rate ($\overset{o}{W}_a$) each	70 lb/sec	31.75 kg/sec
Fan Diameter	59 in.	1.50 m
Maximum Fuel	18,000 lb	8,165 kg
Length	57.7 ft	17.28 m
Span	45 ft	13.71 m
Height	22 ft	6.7 m
Areas		
Wing	432 ft^2	40.13 m^2
Horizontal Tail	88 ft^2	8.18 m^2
Vertical Tail	68 ft^2	6.32 m^2
Aspect Ratio (Wing)	4.7	4.7
Airfoil (Wing)	Supercritical	-
Maximum Cruise Speed	0.83 Mach	0.83 Mach
Service Ceiling	36,000 ft	10,973 m
Estimated Cost	$3,670,800	-

[a] Sea Level ISA

Source: McDonnell Aircraft Company

Specific performance data, such as cruise and climb speeds, and fuel consumption rates, are not available as functions of aircraft weights and operating altitudes. Therefore, using the aircraft geometric parameters, engine performance and aerodynamic data, the thrust required versus speed and climb angles for various altitudes and aircraft weights were computed. These computations were the basis for the curves included in the appendix and the performance coefficients in Table 4-2.

The 75 entries in Table 4-2 completely describe the lift fan aircraft for the purpose of the mission analysis program. This table is a printout of the computer data base for the lift fan aircraft. The following discussion provides the explanation necessary to interpret the name associated with each parameter and its purpose.

The alternate maximum takeoff weight (Alt Max TOWt) provides a means of permitting different weights for aircraft that operate in two modes, having different weight restrictions. In this case, the normal weight is for the lift fan aircraft as a VTOL, while the alternate is for the aircraft as a STOL. (The alternate is also used in the case of some helicopters to indicate an external load, where the external load takeoff weight differs from the normal takeoff weight.)

The abbreviations "Const," "Cof 1," and "Cof 2" refer to the coefficients K_1, K_2, and K_3, respectively, in the general linear function:

$$f = K_1 + K_2 \text{ x altitude (ft)} + K_3 \text{ x weight (lb)}.$$

Applying these coefficients at a given altitude and weight will yield the speeds, fuel flows, etc., used in the analysis.

Alternate climb speed permits two speed conditions to exist which may be selected by appropriate flagging in the mission definition. One such requirement exists in the case of a helicopter with an external load which may climb at a slower speed than normal. Where an aircraft had no defined alternate climb speed, the normal climb speed was used for this parameter.

PARAMETER NAME	UNITS	VALUE
MAX T.O. WT	LBS	35850.0000000000000
ALT MAX T.O. WT	LBS	45000.0000000000000
OP WT EMPTY	LBS	20171.0000000000000
MAX PAX CAPY	NO	23.0000000000000
MAX FUEL CAPY	GAL	2770.0000000000000
NOM CLIMB SPEED CONST	KTS	20.0000000000000
NOM CLIMB SPEED COF1	KTS/FT	.0038880000000
NOM CLIMB SPEED COF2	KTS/LB	.0040000000000
ALT CLIMB SPEED CONST	KTS	20.0000000000000
ALT CLIMB SPEED COF1	KTS/FT	.0038880000000
ALT CLIMB SPEED COF2	KTS/LB	.0040000000000
NOM CRUISE SPEED CONST	KTS	480.0000000000000
NOM CRUISE SPEED COF1	KTS/FT	-.0016700000000
NOM CRUISE SPEED COF2	KTS/LB	.0000000000000
ALT CRUISE SPEED CONST	KTS	120.0000000000000
ALT CRUISE SPEED COF1	KTS/FT	.0030500000000
ALT CRUISE SPEED COF2	KTS/LB	.0040000000000
LOITER SPEED CONST	KTS	20.0000000000000
LOITER SPEED COF1	KTS/FT	.0038880000000
LOITER SPEED COF2	KTS/LB	.0040000000000
NOM R.O.C. CONST	FT/MIN	6750.0000000000000
NOM R.O.C. COF1	FT/MIN/FT	-.1000000000000
NOM R.O.C. COF2	FT/MIN/LB	-.0700000000000
ALT R.O.C. CONST	FT/MIN	6750.0000000000000
ALT R.O.C. COF1	FT/MIN/FT	-.1000000000000
ALT R.O.C. COF2	FT/MIN/LB	-.0700000000000
NOM RATE OF DESCENT	FT/MIN	1000.0000000000000
ALT RATE OF DESCENT	FT/MIN	1500.0000000000000
IDLE/TAXI FUEL CONST	LBS/MIN	101.0000000000000
IDLE/TAXI FUEL COF	LBS/MIN/FT	-.0018800000000
NOM T.O. FUEL CONST	LB/MIN	254.0000000000000
NOM T.O. FUEL COF1	LB/MIN/FT	.0032000000000
NOM T.O. FUEL COF2	LB/MIN/LB	.0000000000000
ALT T.O. FUEL CONST	LB/MIN	254.0000000000000
ALT T.O. FUEL COF1	LB/MIN/FT	-.0092000000000
ALT T.O. FUEL COF2	LB/MIN/LB	.0000000000000
NOM CLIMB FUEL CONST	LBS/MIN	67.0000000000000
NOM CLIMB FUEL COF1	LBS/MIN/FT	-.0015000000000
NOM CLIMB FUEL COF2	LBS/MIN/LB	.0015000000000
ALT CLIMB FUEL CONST	LB/MIN	67.0000000000000

PARAMETER NAME	UNITS	VALUE
ALT CLIMB FUEL COF1	LB/MIN/FT	-.00150000000500
ALT CLIMB FUEL COF2	LB/MIN/LB	.00100000000500
NOM CRUISE FUEL CONST	LBS/MIN	92.0000000000000
NOM CRUISE FUEL COF1	LBS/MIN/FT	-.0020600000000
NOM CRUISE FUEL COF2	LBS/MIN/LB	.0010000000000
ALT CRUISE FUEL CONST	LBS/MIN	12.7500000000000
ALT CRUISE FUEL COF1	LBS/MIN/FT	-.00043100000500
ALT CRUISE FUEL COF2	LBS/MIN/LB	.00145000000500
HOVER FUEL CONST	LBS/MIN	-.0000000000000
HOVER FUEL COF1	LBS/MIN/FT	-.0100000000000
HOVER FUEL COF2	LBS/MIN/LB	.0060000000000
LOITER FUEL CONST	LBS/MIN	6.5000000000000
LOITER FUEL COF1	LBS/MIN/FT	-.0002160000000
LOITER FUEL COF2	LBS/MIN/LB	.0017600000000
COST AIRCRAFT NEW	DOLLARS	3670000.0000000000000
COST AUX EQUIP	DOLLARS	50000.0000000000000
INS PREMIUM	PERCENT/YR	8.0000000000000
SALARY-CREW	DOL/YR EA	20000.0000000000000
MAINT LABOR	HR/FLT HR	.0000000000000
MAINT PARTS	DOL/FLT HR	300.0000000000000
NOM FLIGHT CREW	NO	2.0000000000000
TYPE FUEL (AVGAS=0)	(JP=1)	1.0000000000000
COST FUEL	DOL/GAL	.5000000000000
COST LUBRICANTS	DOL/HR	1.0000000000000
RES FUEL NORMAL CRUISE?	YES=1:NO=0	.0000000000000
FUEL EST FACTOR	N/A	1.0400000000000
SER CEILING CONST	FT	36000.0000000000000
SER CEILING COF	FT/LB	.0000000000000
BREAK ALT HI ALT CRUISE	FT	37000.0000000000000
HI ALT CRUISE CONST	KTS	480.0000000000000
HI ALT CRUISE COF1	KTS/FT	-.0016700000000
HI ALT CRUISE COF2	KTS/LB	.0000000000000
HI ALT FUEL CONST	LBS/MIN/LB	92.0000000000000
HI ALT FUEL COF1	LBS/MIN/FT	-.0020600000000
HI ALT FUEL COF2	LBS/MIN/LB	.0010000000000

Table 4-2. Lift Fan Aircraft Definition Parametric Values

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Normal cruise speed, for the purpose of this table, is the maximum cruise speed, while alternate cruise speed provides maximum range. The loiter speed is used for holding, search, or loiter.

Nominal (NOM) and alternate rates of climb (R.O.C.) are defined to take into account cases in which different climb speeds may be employed.

Nominal and alternate rates of descent are provided to give the analyst this flexibility if desired.

The program also provides for nominal and alternate takeoff conditions in the event it is desirable for some missions to use differing power levels. In the missions analyzed, full thrust was applied for takeoff, and this option was not employed.

The various nominal and alternate fuel flow rates correspond to their related takeoff, climb, and cruise conditions.

The next few items are self-explanatory; however, the type of fuel used must be specified to adjust the weight of fuel loaded and burned off during the mission. Jet fuel or aviation gasoline are optionally selected.

The reserve fuel normal cruise question selects the basis upon which reserve fuel is calculated, either normal cruise (yes) or alternate cruise (no). Selecting normal cruise results in the maximum speed fuel flow rate being used for reserve fuel calculations, while alternate fuel selection results in maximum range fuel flow being used in this calculation. The latter, of course, results in less fuel being placed in reserve.

The fuel estimating factor is used when employing the fuel estimating option explained in Volume II.

The service ceiling[1] is defined by two coefficients. This establishes the highest cruising altitude for the aircraft of a given weight. It will initially climb to this altitude provided that the mission analysis introduces

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[1] This is not the classical definition of service ceiling (i.e., the altitude at which rate of climb equals 100 ~~fmp~~ fpm). Instead, this altitude was limited in some way by the operational performance data such as, a design limitation or an altitude beyond which the non-linearity of the data caused significant departures from the linear assumptions.

no other considerations, such as a maximum desirable cruise altitude or a range too short to permit the climb.

Where the linear function could result in significant error at altitude if cruise is maintained for an appreciable time, it is possible to minimize errors by selecting a high altitude cruise above the break altitude. The last six coefficients define the speed and fuel flow rates used above the altitude defined.

The vertical takeoff weight function shown in Figure 4-2 was derived from engine performance data as a function of altitude. It represents the lift available for the one-minute operating constraint on the three gas generators and three fans with approximately 10% thrust margin for aircraft control. Also included are the ground effects and the installation losses due to ducting as configured for the VTO mode

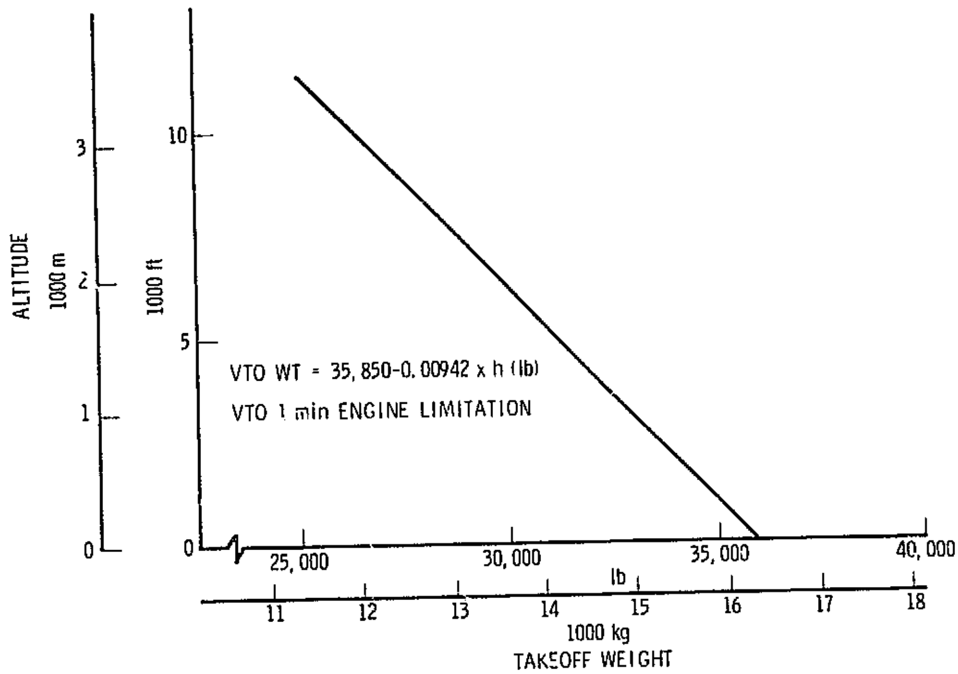

Figure 4-2. Lift Fan Aircraft VTO Weight Versus Altitude - ISA

2. ECONOMIC DATA

The basic reference data on the lift fan aircraft has little information relative to costs; however, it has a detailed component weight breakdown. Using the component weights, it was possible to make an estimate of the aircraft flyaway cost. The aircraft was assumed to be procured for the military, and a production run of 100 civil aircraft was assumed. The unit cost of production was estimated to be $3.52 million each. Additionally, it was assumed that a total of $15 million will be required to make minor civil modifications, build a civil prototype, and conduct a civil aircraft certification program. These certification costs are borne by the 100 aircraft and, therefore, raise the flyaway price of the civil utility lift fan to $3.67 million each.

Controversy is generally provoked when one attempts to estimate the costs of future technology aircraft. This study estimated the flyaway costs of the new aircraft in what was believed a consistent manner; however, some may feel that the costs used are not truly representative. Therefore, a cost sensitivity analysis was performed using the executive transport mission as a typical mission. Assuming a utilization of 800 hours per year, it was found for the lift fan that total hourly operating costs varied 0.3 of one percent for each one percent change in the flyaway cost. This change affected the insurance, depreciation and interest cost elements.

The maintenance costs estimates from several sources range from as low as $200 per flight hour to as high as $400 per flight hour. These figures are highly dependent upon the type of mission flown, the maintenance policies of the operator, the training and skill level of the operating and maintenance personnel, and the number of hours of annual utilization, among other items. They also depend upon whether maintenance burden is included, or not.

A study performed for NASA (Reference (3)) analyzed the direct

maintenance costs of contemporary scheduled airlines, using large helicopters. Results of this study, as well as independent assessments of current CAB data on such air carrier maintenance costs, were used to arrive at reasonable maintenance costs for all aircraft involved in the study. A figure was selected which is believed to be generally applicable to the wide range of missions envisioned in the analysis, and one which includes some portion, at least, of the indirect maintenance costs, or burden.

A large fleet operator of the Falcon 30 indicated that by doing all of the maintenance that they consider economical, their average costs ranged from $125-140 per flight hour. The lift fan aircraft, though more complex, is basically in the same weight class as the Falcon 30; this provides some contemporary calibration to the estimates. The $200-per-flight-hour estimate is felt to be too low, considering the broad range of missions analyzed. Also, it is felt that a conservative figure is more appropriate to such a study than one which is too optimistic.

Therefore, a figure of $300 per flight hour was assumed for the lift fan aircraft's general maintenance cost. This figure considers that some missions may require more hovering than normally expected for landing and takeoff. This hovering, even though time limited, imposes additional stress on the power system and would result in higher maintenance costs.

Maintenance costs can be controversial; additionally, they depend to some degree upon the type of mission flown. Therefore, a sensitivity analysis was conducted to indicate the effect of maintenance costs on overall operating costs of the lift fan aircraft. This analysis assumed an annual utilization of 1000 hours and showed that a variation of one percent in maintenance costs changes the total operating costs by 0.275 percent. Thus, it would require a 36-percent change in maintenance costs to effect a 10-percent change in operating costs.

B. TILT ROTOR AIRCRAFT DEFINITION

1. PERFORMANCE DATA

The tilt rotor concept used in this study is a design by Boeing Vertol for the Naval Air Systems Command. Design and performance data were obtained from reference (4) and from special studies conducted by NASA Ames Research Center. The referenced report describes three basic approaches to the design for both Marine Assault and Navy Anti-Submarine Warfare (ASW) missions. The approach selected provided a single compromise aircraft to best meet both missions. Technology assumptions were based upon Boeing Vertol data adjusted to account for the Utility Tactical Transport Aircraft System (UTTAS) and the Heavy Lift Helicopter (HLH) experience. The maximum speed of this rigid rotor design is 300 knots (154 m/sec). Figure 4-3 shows the tilt rotor external configuration with dimensional data. Table 4-3 presents tilt rotor dimensional and design data.

The Boeing Vertol report provides performance data directly; therefore, it was unnecessary, as in the case of the lift fan, to develop performance from the basic aerodynamic equations. However, the performance data only exist at one weight for two variants of the design, a Navy ASW design and a Marine Assault design. Since these two designs employ the same basic airframe and engine (differing principally in fuel tankage, weapons, and electronics only), and since their performance data are presented for different gross weights, it was possible to treat these data as one design at two gross weights and develop the necessary performance curves.

The coefficients presented in Table 4-4 were obtained from these curves (contained in the appendix). Since the format of Table 4-4 is identical to that previously discussed regarding the lift fan aircraft, no further explanation is offered.

The basic Navy and Marine mission design does not employ pressurization; however, this report provided for pressurization weight allowances

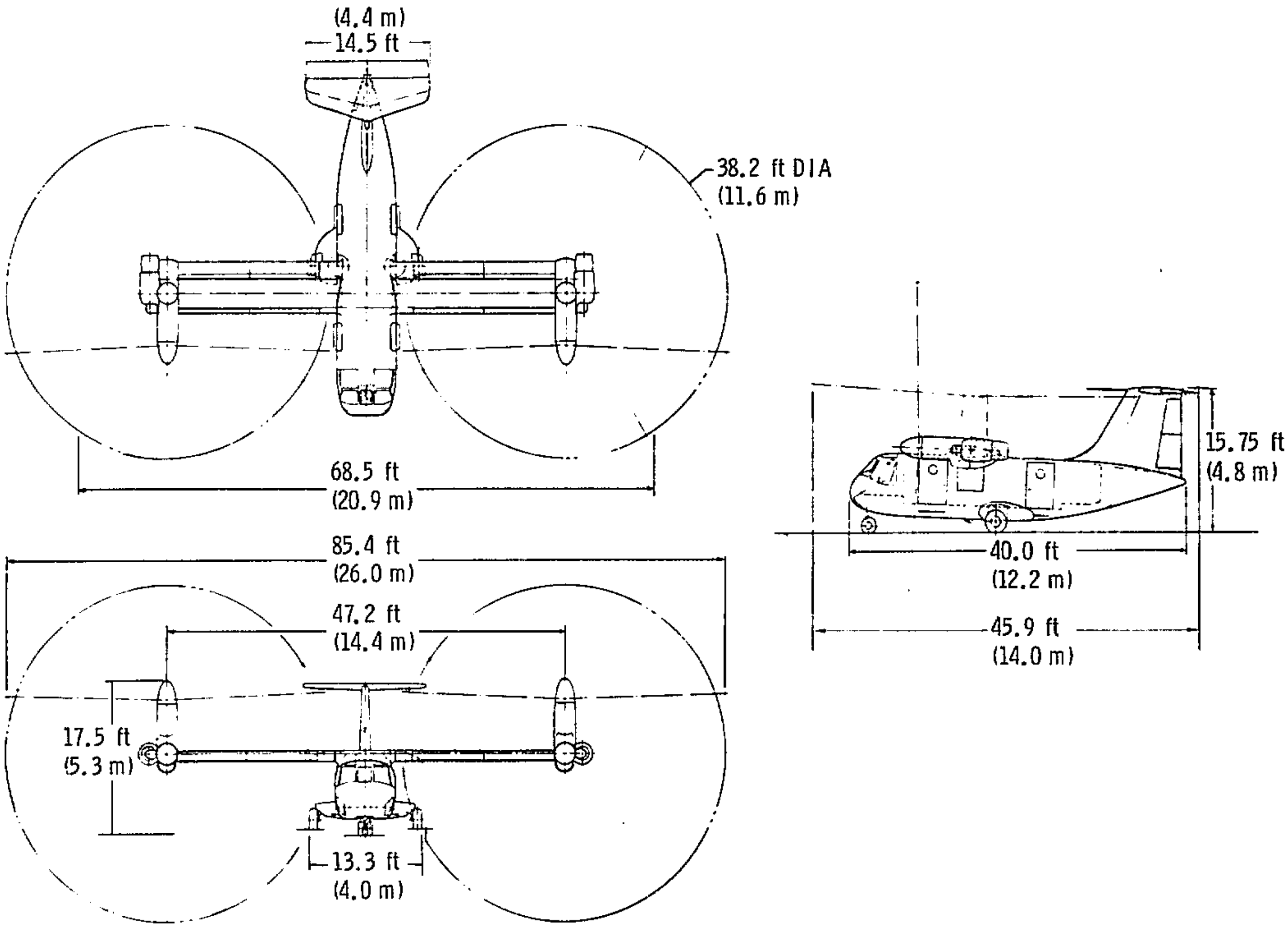

Figure 4-3. Tilt Rotor External Configuration

Source: Boeing Vertol Company

Table 4-3. Tilt Rotor Description Parametric Summary

Parameter	Value English	Value Metric
Takeoff Gross Weight[a] VTO	33,500 lb	15,196 kg
Operating Weight Empty	18,588 lb	8,499 kg
Installed Power	5,201 SHP	388 W
Maximum Fuel	7,639 lb	3,465 kg
Length[b]	40 ft	12.19 m
Length[c]	44.8 ft	13.66 m
Width[b]	47.2 ft	13.39 m
Width[c]	85.4 ft	26.02 m
Height	15.75 ft	4.8 m
Rotor Diameter	38.2 ft	11.6 m
Rotor Solidity	0.070	0.070
Disc Loading	13.9 lb/ft^2	665.5 n/m^2
Hover Tip Speed	825 fps	251.46 m/sec
Cruise Tip Speed	578 fps	176.17 m/sec
Wing Area	279 ft^2	25.92 m^2
Wing Loading	114 lb/ft^2	54,583 n/m^2
Aspect Ratio (Wing)	7.97	7.97
Seating (Passengers)	32	32
Crew (Seats)	3	3
Maximum Cruise Speed	300 kts	154 m/sec
Service Ceiling[d]	17,667 ft	5,385 m
Cost	$2,830,000	-

[a] Sea Level ISA

[b] Not Including Rotors

[c] Rotor Turning

[d] Maximum Weight

Source: Boeing Vertol Company

PARAMETER NAME	UNITS	VALUE
MAX T.O. WT	LBS	33000.0000000000000
ALT MAX T.O. WT	LBS	33000.0000000000000
OP WT EMPTY	LBS	18758.0000000000000
MAX PAX CAPY	NO	23.0000000000000
MAX FUEL CAPY	GAL	1140.0000000000000
NOM CLIMB SPEED CONST	KTS	112.0000000000000
NOM CLIMB SPEED COF1	KTS/FT	.0030000000000
NOM CLIMB SPEED COF2	KTS/LB	.0033900000000
ALT CLIMB SPEED CONST	KTS	112.0000000000000
ALT CLIMB SPEED COF1	KTS/FT	.0030000000000
ALT CLIMB SPEED COF2	KTS/LB	.0033900000000
NOM CRUISE SPEED CONST	KTS	396.0000000000000
NOM CRUISE SPEED COF1	KTS/FT	-.0013960000000
NOM CRUISE SPEED COF2	KTS/LB	-.0030000000000
ALT CRUISE SPEED CONST	KTS	2.0000000000000
ALT CRUISE SPEED COF1	KTS/FT	.0062900000000
ALT CRUISE SPEED COF2	KTS/LB	.0066700000000
LOITER SPEED CONST	KTS	22.0000000000000
LOITER SPEED COF1	KTS/FT	.0027700000000
LOITER SPEED COF2	KTS/LB	.0038100000000
NOM R.O.C. CONST	FT/MIN	7757.0000000000000
NOM R.O.C. COF1	FT/MIN/FT	-.1389000000000
NOM R.O.C. COF2	FT/MIN/LB	-.1464400000000
ALT R.O.C. CONST	FT/MIN	7757.0000000000000
ALT R.O.C. COF1	FT/MIN/FT	-.1389000000000
ALT R.O.C. COF2	FT/MIN/LB	-.1464400000000
NOM RATE OF DESCENT	FT/MIN	1000.0000000000000
ALT RATE OF DESCENT	FT/MIN	1500.0000000000000
IDLE/TAXI FUEL CONST	LBS/MIN	5.6000000000000
IDLE/TAXI FUEL COF	LBS/MIN/FT	.0000000000000
NOM T.O. FUEL CONST	LB/MIN	38.0000000000000
NOM T.O. FUEL COF1	LB/MIN/FT	-.0008500000000
NOM T.O. FUEL COF2	LB/MIN/LB	.0000000000000
ALT T.O. FUEL CONST	LB/MIN	38.0000000000000
ALT T.O. FUEL COF1	LB/MIN/FT	-.0008500000000
ALT T.O. FUEL COF2	LB/MIN/LB	.0000000000000
NOM CLIMB FUEL CONST	LBS/MIN	38.0000000000000
NOM CLIMB FUEL COF1	LBS/MIN/FT	-.0008500000000
NOM CLIMB FUEL COF2	LBS/MIN/LB	.0000000000000
ALT CLIMB FUEL CONST	LB/MIN	38.0000000000000

PARAMETER NAME	UNITS	VALUE
ALT CLIMB FUEL COF1	LB/MIN/FT	-.00085000000500
ALT CLIMB FUEL COF2	LB/MIN/LB	.00000000000500
NOM CRUISE FUEL CONST	LBS/MIN	35.0000000000000
NOM CRUISE FUEL COF1	LBS/MIN/FT	-.00072450000000
NOM CRUISE FUEL COF2	LBS/MIN/LB	.0000000000000
ALT CRUISE FUEL CONST	LBS/MIN	-12.0000000000000
ALT CRUISE FUEL COF1	LBS/MIN/FT	.00021700000500
ALT CRUISE FUEL COF2	LBS/MIN/LB	.00119000000500
HOVER FUEL CONST	LBS/MIN	4.7800000000000
HOVER FUEL COF1	LBS/MIN/FT	-.00082216000000
HOVER FUEL COF2	LBS/MIN/LB	.00089864000000
LOITER FUEL CONST	LBS/MIN	-6.0000000000000
LOITER FUEL COF1	LBS/MIN/FT	.00023600000000
LOITER FUEL COF2	LBS/MIN/LB	.00079400000000
COST AIRCRAFT NEW	DOLLARS	2830000.0000000000000
COST AUX EQUIP	DOLLARS	50000.0000000000000
INS PREMIUM	PERCENT/YR	8.0000000000000
SALARY-CREW	DOL/YR EA	20000.0000000000000
MAINT LABOR	HR/FLT HR	.0000000000000
MAINT PARTS	DOL/FLT HR	300.0000000000000
NOM FLIGHT CREW	NO	2.0000000000000
TYPE FUEL (AVGAS=0)	(JP=1)	1.0000000000000
COST FUEL	DOL/GAL	.5000000000000
COST LUBRICANTS	DOL/HR	1.0000000000000
RES FUEL NORMAL CRUISE?	YES=1:NO=0	.0000000000000
FUEL EST FACTOR	N/A	1.0100000000000
SER CEILING CONST	FT	54333.0000000000000
SER CEILING COF	FT/LB	-1.1111000000000
BREAK ALT HI ALT CRUISE	FT	16000.0000000000000
HI ALT CRUISE CONST	KTS	611.0000000000000
HI ALT CRUISE COF1	KTS/FT	-.00736000000000
HI ALT CRUISE COF2	KTS/LB	-.00736060000000
HI ALT FUEL CONST	LBS/MIN/LB	35.0000000000000
HI ALT FUEL COF1	LBS/MIN/FT	-.00072450000000
HI ALT FUEL COF2	LBS/MIN/LB	.0000000000000

Table 4-4. Tilt Rotor Aircraft Definition Parametric Values

which were added to the Navy aircraft empty weight. Adjustments to the empty weight were also made for adding passenger accommod .ons, civil avionics, and the removal of armament. Takeoff weight was adjusted from the specified Sea Level - 90°F (32°C) condition to Sea Level ISA. No STOL performance data were provided; therefore, it was assumed for this study that the tilt rotor only operates in the VTOL mode, although the STOL mode is acceptable for several missions (as indicated later in discussions of the lift fan aircraft). If operable as a STOL, improved productivity is expected.

Figure 4-4 shows the takeoff weight capability versus altitude. This information was not available from the primary reference for the tilt rotor and was provided by NASA Ames Research Center as developed by the computer program VASCOMP.

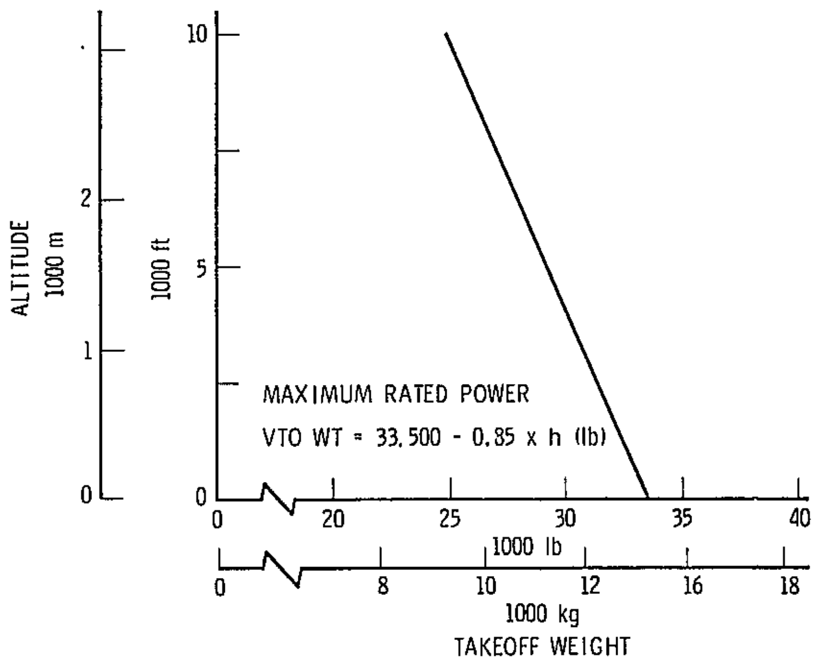

Figure 4-4. Tilt Rotor VTO Weight Versus Altitude - ISA

Source: NASA

2. ECONOMIC DATA

The Boeing Vertol data source indicated a range of delivery costs for the military aircraft from \$2.14 to \$3.70 million, depending upon whether the Navy or Marine configuration was involved, and also relative to the Navy configuration in quantities delivered. Correcting these costs to the Navy configuration (without mission avionics) for a total of 737 aircraft, the production costs (no R&D) ran as high as \$2.27 million per aircraft. To this cost for each aircraft was added the sum of \$150 thousand for certification costs, and \$310 thousand to cover cost of design and installation of a pressurization system, plus a contingency allowance for a smaller production run. The result was the assumption of a \$2.83 million flyaway cost for the civil utility version.

The cost sensitivity analysis for the tilt rotor showed a slightly greater influence of the flyaway cost on hourly costs than was the case for the lift fan. A one percent change in the purchase price of the tilt rotor is reflected as a 0.4 percent change in the hourly operating cost.

As in the case of the lift fan aircraft, \$300 per flight hour were assumed for the tilt rotor maintenance costs. It was felt that, unless a clear case was made why one should be less expensive than the other, no hourly cost penalty should be imposed on either concept. While the rigid rotor system holds promise of less maintenance than current complex rotor systems used on helicopters, the mechanism to tilt the rotors, plus the required cross shafting, appeared to require maintenance comparable to the lift fan aircraft. For these reasons, the conservative \$300 figure was felt to be justified. The tilt rotor operating cost sensitivity to changes in maintenance cost was 0.426 percent per percent change of hourly maintenance costs. A 23-percent change in maintenance costs would result in a 10-percent change in operating costs. Thus, the tilt rotor is slightly more sensitive to errors in maintenance costs than is the lift fan aircraft.

C. ADVANCED HELICOPTER DEFINITION

1. PERFORMANCE DATA

An advanced helicopter design was selected for this study which served as a baseline for comparison to the other two advanced VTOL concepts. The Boeing Vertol design described in reference (4) was chosen since it was felt to be consistent in design detail and approach with the tilt rotor design. As was the case of the tilt rotor, the Boeing Vertol advanced helicopter was designed to meet the requirements of several Navy missions and a Marine assault mission. The reference report proposes several advanced helicopters, including compound helicopters. The 180 knot (93 m/sec) advanced helicopter was designated for use in this study. Figure 4-5 shows the external configuration of the advanced helicopter. The technology base for this helicopter was the UTTAS and HLH with no additional state-of-the-art advances in rotor and drive systems. Engine structural materials and flight control technology was the same as for the tilt rotor. Table 4-5 contains both dimensional and design data for the advanced helicopter.

Advanced helicopter data in reference (4) were essentially to the same level of detail as described in the previous section on the tilt rotor. Therefore, the hover and takeoff performance data not available from the Boeing Vertol report were supplied by NASA Ames Research Center. In the case of the advanced helicopter, data were available for three different aircraft weights for the Navy design. The resulting performance curves used in this study are shown in Volume II. Performance data were corrected as required to represent sea level ISA conditions instead of sea level 90°F (32°C). Also, empty weights were adjusted to be representative of civil use. An unpressurized helicopter was assumed.

Figure 4-6 shows the results of the NASA computation of takeoff weights, using the HESCOMP computer program. Both normal rated power (NRP) and maximum rated power (MRP) curves are shown. The Boeing Vertol design for sea level - 90°F (32°C) at intermediate rated power is

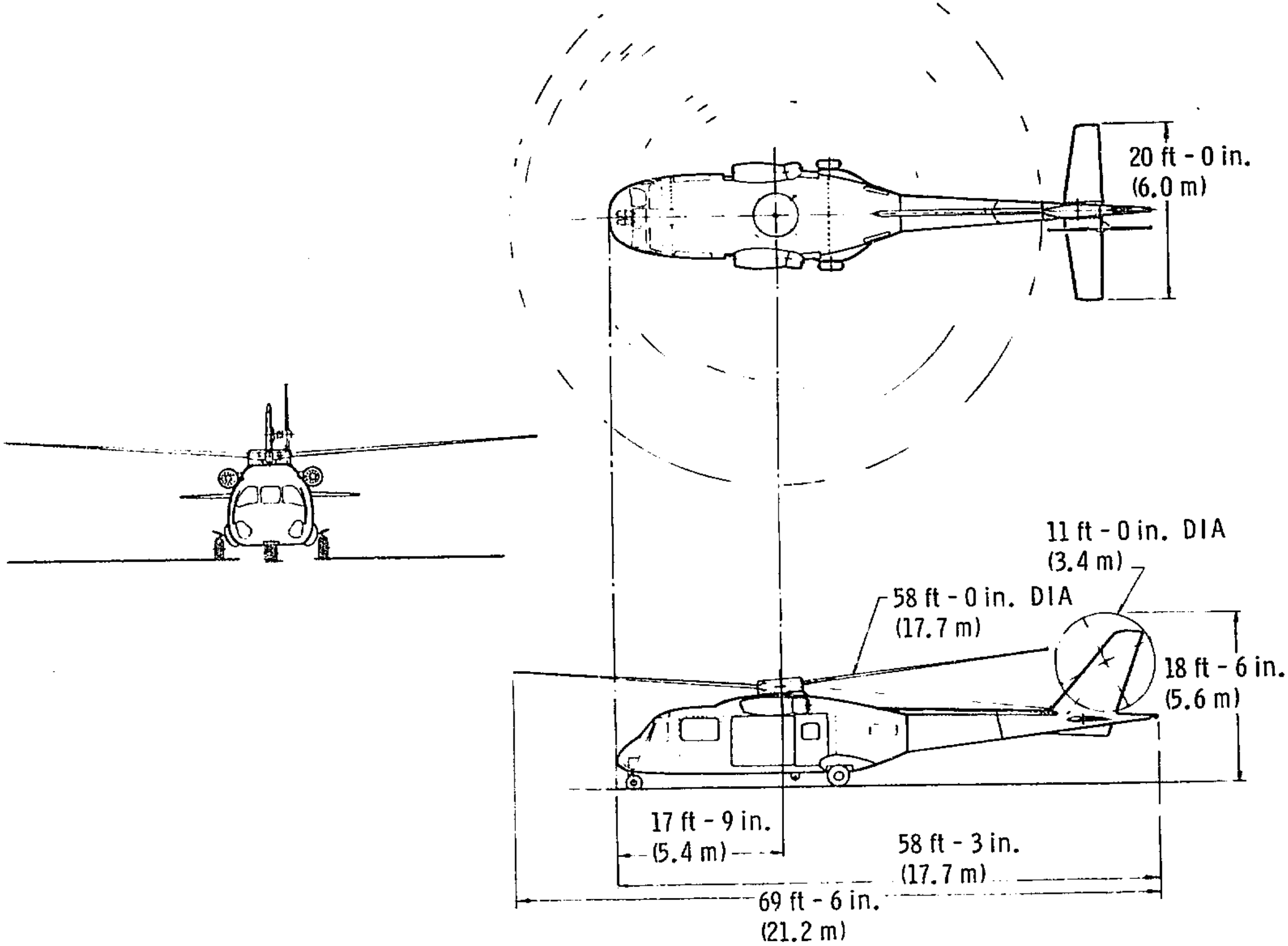

Figure 4-5. Advanced Helicopter External Configuration

Source: Boeing Vertol Co.

Table 4-5. Advanced Helicopter Parametric Summary

Parameter	Value: English	Value: Metric
Takeoff Gross Weight[a]	31, 500 lb	14, 288 kg
Operating Weight Empty	14, 578 lb	6, 612 kg
Installed Power	5, 892 SHP	4, 394 kw
Maximum Fuel	8, 574 lb	3, 889 kg
Length[b]	58. 25 ft	17. 96 m
Length[c]	69. 5 ft	21. 43 m
Width[b]	12 ft	3. 66 m
Width[c]	58 ft	17. 68 m
Height	18. 5 ft	5. 64 m
Rotor Diameter	58 ft	17. 68 m
Rotor Solidity	0. 088	0. 088
Disc Loading	11. 0 lb/ft^2	526. 68 n/m^2
Hover Tip Speed	775 fps	236 m/sec
Cruise Tip Speed	775 fps	236 m/sec
Seating (Passengers)	23	23
Crew (Seats)	3	3
Maximum Cruise Speed	180 kts	92. 6 m/sec
Service Ceiling[d]	10, 000 ft	3, 048 m
Cost	$2, 500, 000	-

[a] Sea Level ISA

[b] Not Including Rotor, Horizontal Tail Folded

[c] Rotor Turning

[d] Maximum Gross Weight

Source: Boeing Vertol Company

approximately equivalent to 2000 ft - ISA (610 m - ISA). Takeoff weight for this point is given as 29,944 lb (13582 kg). This data point is shown; it corresponds to an NRP takeoff weight on the NASA curve. The MRP curve represents the Navy overload condition. This study assumed the use of NRP for takeoff.

Table 4-6 provides the 75 aircraft definition parameters similar to those discussed for the previous two aircraft. As with the other concepts, maximum cruise speed is used for normal cruise.

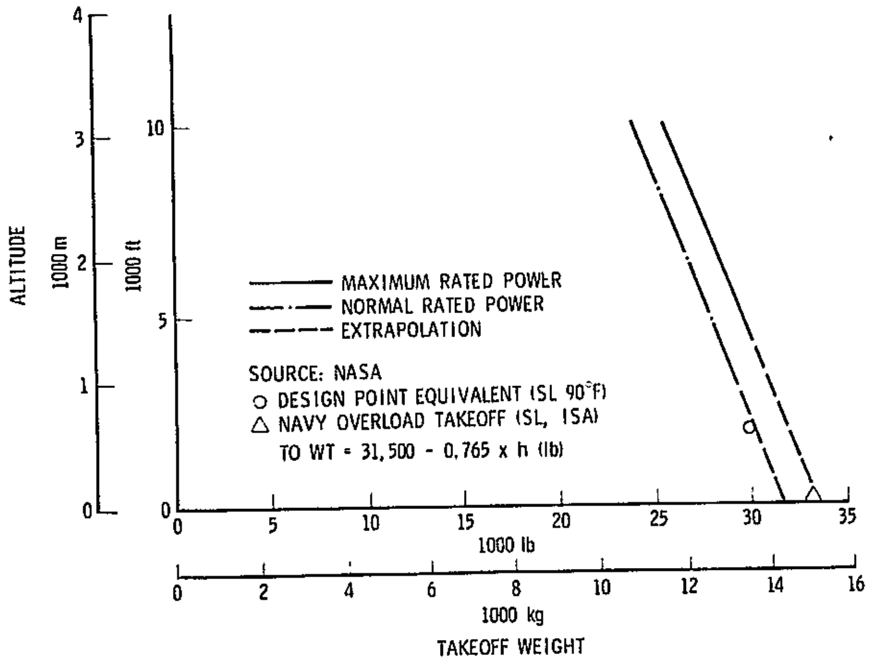

Figure 4-6. Advanced Helicopter VTO Weight Versus Altitude - ISA

PARAMETER NAME	UNITS	VALUE
MAX T.O. WT	LBS	31500.00000000000000
ALT MAX T.O. WT	LBS	31500.00000000000000
OP WT EMPTY	LBS	14578.00000000000000
MAX PAX CAPY	NO	23.00000000000000
MAX FUEL CAPY	GAL	1280.00000000000000
NOM CLIMB SPEED CONST	KTS	43.00000000000000
NOM CLIMB SPEED COF1	KTS/FT	.00050000000000
NOM CLIMB SPEED COF2	KTS/LB	.00118400000000
ALT CLIMB SPEED CONST	KTS	43.00000000000000
ALT CLIMB SPEED COF1	KTS/FT	.00050000000000
ALT CLIMB SPEED COF2	KTS/LB	.00118400000000
NOM CRUISE SPEED CONST	KTS	243.00000000000000
NOM CRUISE SPEED COF1	KTS/FT	-.00253000000000
NOM CRUISE SPEED COF2	KTS/LB	-.00210500000000
ALT CRUISE SPEED CONST	KTS	103.00000000000000
ALT CRUISE SPEED COF1	KTS/FT	.00000000000000
ALT CRUISE SPEED COF2	KTS/LB	.00092100000000
LOITER SPEED CONST	KTS	57.00000000000000
LOITER SPEED COF1	KTS/FT	.00065000000000
LOITER SPEED COF2	KTS/LB	.00118400000000
NOM R.O.C. CONST	FT/MIN	10306.00000000000000
NOM R.O.C. COF1	FT/MIN/FT	-.16800000000000
NOM R.O.C. COF2	FT/MIN/LB	-.22760000000000
ALT R.O.C. CONST	FT/MIN	10306.00000000000000
ALT R.O.C. COF1	FT/MIN/FT	-.16800000000000
ALT R.O.C. COF2	FT/MIN/LB	-.22760000000000
NOM RATE OF DESCENT	FT/MIN	500.00000000000000
ALT RATE OF DESCENT	FT/MIN	1000.00000000000000
IDLE/TAXI FUEL CONST	LBS/MIN	6.40000000000000
IDLE/TAXI FUEL COF	LBS/MIN/FT	.00000000000000
NOM T.O. FUEL CONST	LB/MIN	37.00000000000000
NOM T.O. FUEL COF1	LB/MIN/FT	.00085000000000
NOM T.O. FUEL COF2	LB/MIN/LB	.00000000000000
ALT T.O. FUEL CONST	LB/MIN	37.00000000000000
ALT T.O. FUEL COF1	LB/MIN/FT	.00085000000000
ALT T.O. FUEL COF2	LB/MIN/LB	.00000000000000
NOM CLIMB FUEL CONST	LBS/MIN	37.00000000000000
NOM CLIMB FUEL COF1	LBS/MIN/FT	.00085000000000
NOM CLIMB FUEL COF2	LBS/MIN/LB	.00000000000000
ALT CLIMB FUEL CONST	LB/MIN	37.00000000000000
ALT CLIMB FUEL COF1	LB/MIN/FT	.00085000000500
ALT CLIMB FUEL COF2	LB/MIN/LB	.00000000000500
NOM CRUISE FUEL CONST	LBS/MIN	37.00000000000000
NOM CRUISE FUEL COF1	LBS/MIN/FT	-.00085000000000
NOM CRUISE FUEL COF2	LBS/MIN/LB	.00000000000000
ALT CRUISE FUEL CONST	LBS/MIN	.00000000000000
ALT CRUISE FUEL COF1	LBS/MIN/FT	.00000000000500
ALT CRUISE FUEL COF2	LBS/MIN/LB	.00073680000500
HOVER FUEL CONST	LBS/MIN	-3.00000000000000
HOVER FUEL COF1	LBS/MIN/FT	-.00100000000000
HOVER FUEL COF2	LBS/MIN/LB	.00125000000000
LOITER FUEL CONST	LBS/MIN	-.00000000000000
LOITER FUEL COF1	LBS/MIN/FT	-.00002220000000
LOITER FUEL COF2	LBS/MIN/LB	.00065789000000
COST AIRCRAFT NEW	DOLLARS	2510000.00000000000000
COST AUX EQUIP	DOLLARS	25000.00000000000000
INS PREMIUM	PERCENT/YR	8.00000000000000
SALARY-CREW	DOL/YR EA	20000.00000000000000
MAINT LABOR	HR/FLT HR	9.00000000000000
MAINT PARTS	DOL/FLT HR	150.00000000000000
NOM FLIGHT CREW	NO	2.00000000000000
TYPE FUEL (AVGAS=0)	(JP=1)	1.00000000000000
COST FUEL	DOL/GAL	.50000000000000
COST LUBRICANTS	DOL/HR	1.00000000000000
RES FUEL NORMAL CRUISE?	YES=1:NO=0	.00000000000000
FUEL EST FACTOR	N/A	1.00000000000000
SER CEILING CONST	FT	47342.00000000000000
SER CEILING COF	FT/LB	-1.38158000000000
BREAK ALT HI ALT CRUISE	FT	8000.00000000000000
HI ALT CRUISE CONST	KTS	103.00000000000000
HI ALT CRUISE COF1	KTS/FT	.00000000000000
HI ALT CRUISE COF2	KTS/LB	.00092100000000
HI ALT FUEL CONST	LBS/MIN/LB	.00000000000000
HI ALT FUEL COF1	LBS/MIN/FT	.00000000000000
HI ALT FUEL COF2	LBS/MIN/LB	.00073680000000

Table 4-6. Advanced Helicopter Definition Parametric Values

2. ECONOMIC DATA

The referenced report for the advanced helicopter showed a cost range of \$1.84 to \$3.31 million--estimated by the manufacturer. Adjustment to an all-Navy configuration run of 737 aircraft brought the cost per aircraft to \$2.05 million. Adding to this the certification costs of \$150 thousand and another \$300 thousand as a contingency, and also to account for a smaller production run, the flyaway cost assumed for the civil utility version study totaled \$2.5 million.

The cost sensitivity analysis of the advanced helicopter was found equal to that of the tilt rotor, i.e. 0.4 percent change in hourly costs for each one percent change of purchase price.

The Boeing Vertol maintenance estimate of \$170 per flight hour for the Marine helicopter appeared to be a bit optimistic, especially in view of the current costs known to exist for the Falcon 30 (\$125-\$140 per flight hour). A cost of \$240 per flight hour, however, appeared reasonable and gave the helicopter some advantage over the other two advanced concepts, in addition to placing it in a more realistic relationship to the Falcon 30. The maintenance cost sensitivity analysis indicated that the operating costs vary by 0.338 percent per percent change of hourly maintenance costs. Therefore, a 30-percent change in maintenance costs is required to change the operating costs by 10 percent. Thus, the advanced helicopter's sensitivity to errors in maintenance costs falls between that of the lift fan aircraft and the tilt rotor aircraft.

D. CONTEMPORARY AIRCRAFT DEFINITION

In addition to the advanced aircraft described previously, contemporary aircraft (the Falcon 30 and the Sikorsky S-61) were selected for comparison in the mission analyses.

The linearization methods used for the advanced concept aircraft were also employed to represent the contemporary aircraft in a similar fashion.

1. FALCON 30 TURBOFAN

The Falcon 30 is a relatively large business jet manufactured in France. It was selected for comparison purposes since its weight class is closer to that of the advanced concepts than most other business jets. However, it has a larger fuselage than the advanced concepts studied and, therefore, can accommodate a larger passenger load.

Operational data for the Falcon 30 were obtained from reference (5). A general outline configuration of this aircraft is presented in Figure 4-7. A summary of its performance and dimensional data is provided in Table 4-7. Table 4-8 provides the 75 parameters used by the computer analysis program.

Maintenance costs were obtained from a U. S. operator with a large fleet of these aircraft. Their records indicated that hourly maintenance costs ranged from \$125-\$140 per flight hour. This study selected \$130 per flight hour as the cost of maintenance.

2. SIKORSKY S-61 HELICOPTER

The Sikorsky S-61 helicopter was selected for comparison with the advanced concepts in this study since it is commonly employed in the missions being analyzed. Two variations of this helicopter are popular. The S-61 N, because it is amphibious (a characteristic required for the offshore mission), was selected as the comparison model. It is a twin-turbine-engined aircraft, seating 26 passengers. The S-61L is slightly larger, weighs 550 lb (240 kg) less, carries less fuel than the S-61N, and seats 30 passengers.

Figure 4-8 presents the aircraft outline configuration, while Table 4-9 provides the helicopter's parametric summary. Operational data were developed from information in reference (6). The maintenance cost data represent a composite of the information obtained from a variety of

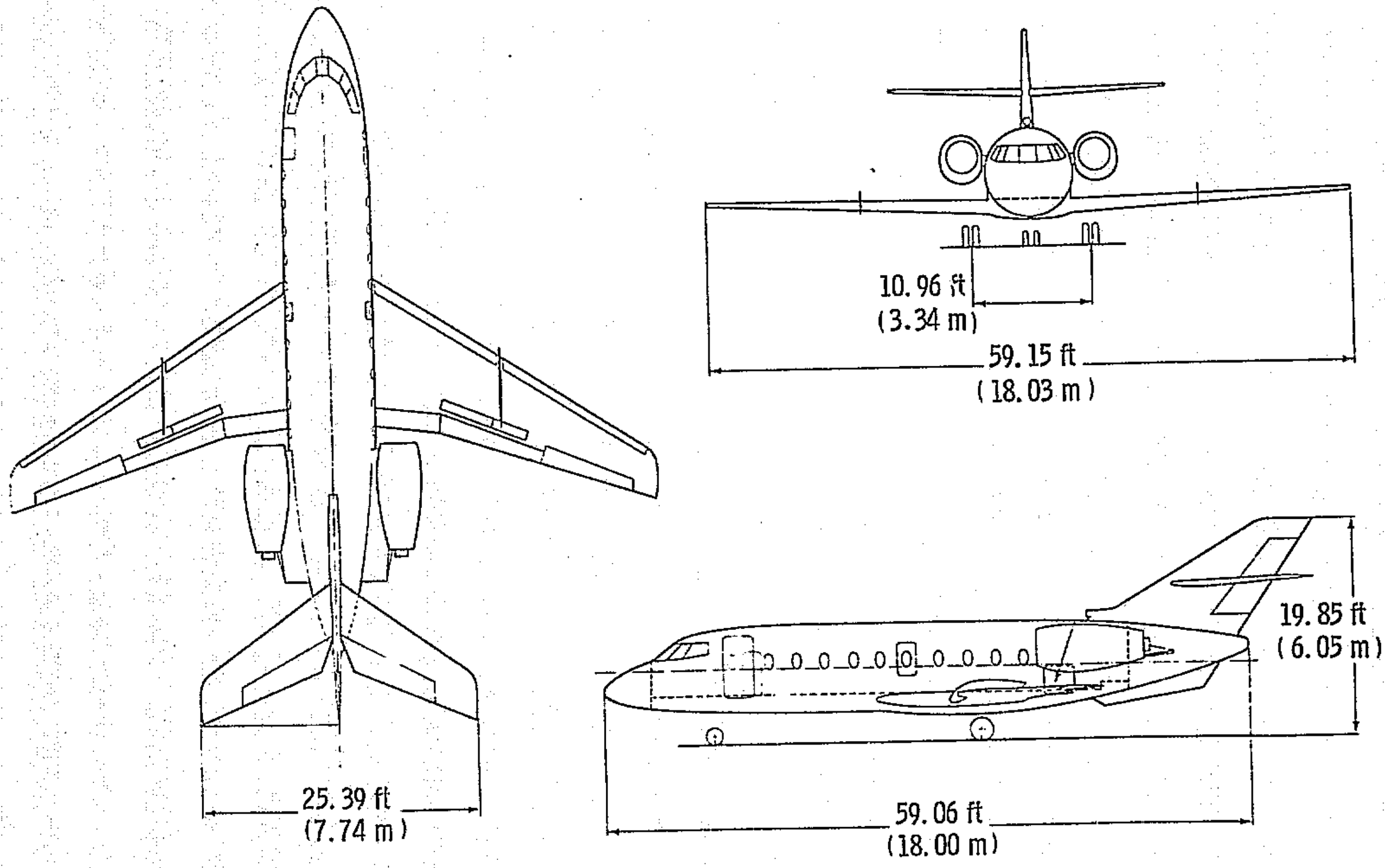

Figure 4-7. Falcon 30 External Configuration

Source: Avions Marcel Dassaoult - Breguet Aviation

Table 4-7. Falcon 30 Parametric Summary

Parameter	Value English	Value Metric
Takeoff Maximum Gross Weight	35,275 lb	16,000 kg
Operating Weight Empty	22,400 lb	10,160 kg
Installed Power (Thrust)[a]	12,140 lb	5,507 kg
Maximum Fuel	9,350 lb	4,241 kg
Length	65.2 ft	19.9 m
Width	59.2 ft	18 m
Height	19.9 ft	6 m
Wing Area	530 ft^2	94.2 m^2
Wing Loading	66.56 lb/ft^2	3,187 n/m^2
Aspect Ratio	6.58	6.58
Seating (Passengers)	40	40
Crew (Seats)	2	2
Maximum Cruise Speed	0.8 Mach	0.8 Mach
Service Ceiling	41,000 ft	12,497 km
Cost	\$3,000,000	-

[a] Two 6:1 Bypass Ratio Avco Lycoming Engines

Source: Avions Marcel Dassault - Breguet Aviation

PARAMETER NAME	UNITS	VALUE
MAX T.O. WT	LBS	35275.0000000000000
ALT MAX T.O. WT	LBS	35275.0000000000000
OP WT EMPTY	LBS	22150.0000000000000
MAX PAX CAPY	NO	40.0000000000000
MAX FUEL CAPY	GAL	1400.0000000000000
NOM CLIMB SPEED CONST	KTS	275.0000000000000
NOM CLIMB SPEED COF1	KTS/FT	.0000000000000
NOM CLIMB SPEED COF2	KTS/LB	.0000000000000
ALT CLIMB SPEED CONST	KTS	275.0000000000000
ALT CLIMB SPEED COF1	KTS/FT	.0000000000000
ALT CLIMB SPEED COF2	KTS/LB	.0000000000000
NOM CRUISE SPEED CONST	KTS	180.0000000000000
NOM CRUISE SPEED COF1	KTS/FT	.0055000000000
NOM CRUISE SPEED COF2	KTS/LB	.0000000000000
ALT CRUISE SPEED CONST	KTS	180.0000000000000
ALT CRUISE SPEED COF1	KTS/FT	.00550000000000
ALT CRUISE SPEED COF2	KTS/LB	.00000000000000
LOITER SPEED CONST	KTS	188.0000000000000
LOITER SPEED COF1	KTS/FT	.00427000000000
LOITER SPEED COF2	KTS/LB	.00000000000000
NOM R.O.C. CONST	FT/MIN	9950.0000000000000
NOM R.O.C. COF1	FT/MIN/FT	-.1200000000000
NOM R.O.C. COF2	FT/MIN/LB	-.1200000000000
ALT R.O.C. CONST	FT/MIN	9950.0000000000000
ALT R.O.C. COF1	FT/MIN/FT	-.1200000000000
ALT R.O.C. COF2	FT/MIN/LB	-.1200000000000
NOM RATE OF DESCENT	FT/MIN	1000.0000000000000
ALT RATE OF DESCENT	FT/MIN	1500.0000000000000
IDLE/TAXI FUEL CONST	LBS/MIN	15.4000000000000
IDLE/TAXI FUEL COF	LBS/MIN/FT	.0000000000000
NOM T.O. FUEL CONST	LB/MIN	85.0000000000000
NOM T.O. FUEL COF1	LB/MIN/FT	.0000000000000
NOM T.O. FUEL COF2	LB/MIN/LB	.0000000000000
ALT T.O. FUEL CONST	LB/MIN	85.0000000000000
ALT T.O. FUEL COF1	LB/MIN/FT	.0000000000000
ALT T.O. FUEL COF2	LB/MIN/LB	.0000000000000
NOM CLIMB FUEL CONST	LBS/MIN	97.0000000000000
NOM CLIMB FUEL COF1	LBS/MIN/FT	.0011000000000
NOM CLIMB FUEL COF2	LBS/MIN/LB	.0000000000000
ALT CLIMB FUEL CONST	LB/MIN	97.0000000000000

PARAMETER NAME	UNITS	VALUE
ALT CLIMB FUEL COF1	LB/MIN/FT	-.00110000000500
ALT CLIMB FUEL COF2	LB/MIN/LB	.0000000000500
NOM CRUISE FUEL CONST	LBS/MIN	2.0000000000000
NOM CRUISE FUEL COF1	LBS/MIN/FT	.0000000000000
NOM CRUISE FUEL COF2	LBS/MIN/LB	.00085000000000
ALT CRUISE FUEL CONST	LBS/MIN	2.0000000000000
ALT CRUISE FUEL COF1	LBS/MIN/FT	.0000000000500
ALT CRUISE FUEL COF2	LBS/MIN/LB	.00085000000500
HOVER FUEL CONST	LBS/MIN	.0000000000000
HOVER FUEL COF1	LBS/MIN/FT	.0000000000000
HOVER FUEL COF2	LBS/MIN/LB	.0000000000000
LOITER FUEL CONST	LBS/MIN	7.4250000000000
LOITER FUEL COF1	LBS/MIN/FT	-.00019700000000
LOITER FUEL COF2	LBS/MIN/LB	.00076000000000
COST AIRCRAFT NEW	DOLLARS	3000000.0000000000000
COST AUX EQUIP	DOLLARS	50000.0000000000000
INS PREMIUM	PERCENT/YR	1.0000000000000
SALARY-CREW	DOL/YR EA	20000.0000000000000
MAINT LABOR	HR/FLT HR	4.0000000000000
MAINT PARTS	DOL/FLT HR	90.0000000000000
NOM FLIGHT CREW	NO	2.0000000000000
TYPE FUEL (AVGAS=0)	(JP=1)	1.0000000000000
COST FUEL	DOL/GAL	.5000000000000
COST LUBRICANTS	DOL/HR	1.0000000000000
RES FUEL NORMAL CRUISE?	YES=1:NO=0	1.0000000000000
FUEL EST FACTOR	N/A	1.0000000000000
SER CEILING CONST	FT	61666.0000000000000
SER CEILING COF	FT/LB	-.7560000000000
BREAK ALT HI ALT CRUISE	FT	41000.0000000000000
HI ALT CRUISE CONST	KTS	.0000000000000
HI ALT CRUISE COF1	KTS/FT	.0000000000000
HI ALT CRUISE COF2	KTS/LB	.0000000000000
HI ALT FUEL CONST	LBS/MIN/LB	.0000000000000
HI ALT FUEL COF1	LBS/MIN/FT	.0000000000000
HI ALT FUEL COF2	LBS/MIN/LB	.0000000000000

Table 4-8. Falcon 30 Definition Parametric Values

companies operating the S-61. The cost of maintenance per flight hour was assumed to be $240. Table 4-10 provides the listing of all 75 parameters used to describe the S-61 for this study.

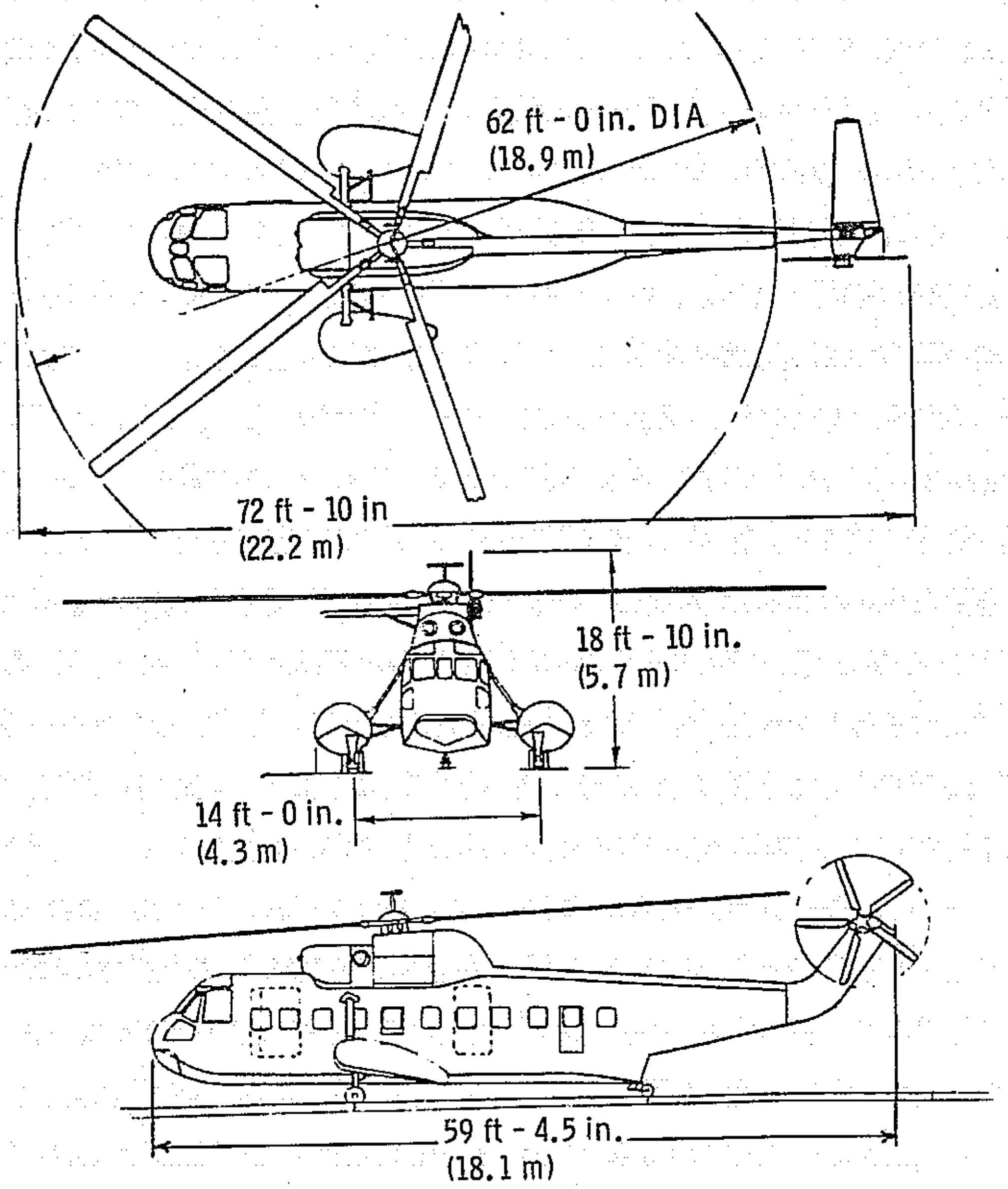

Figure 4-8. Sikorsky S-61N Helicopter External Configuration

Source: Sikorsky Aircraft

Table 4-9. Sikorsky S-61N Helicopter Parametric Summary

Parameter	Value English	Value Metric
Takeoff Gross Weight[a]	19000 lb	862 kg
Operating Weight Empty	12860 lb	5833 kg
Installed Power[b]	3000 SHP	2237 kw
Maximum Fuel[c]	2747 lb	1246 kg
Length[d]	59.4 ft	18.1 m
Length[e]	72.8 ft	22.2 m
Width[d]	14.3 ft	4.4 m
Width[e]	62 ft	18.9 m
Height	17 ft	5.2 m
Rotor Diameter	62 ft	18.9 m
Disc Loading	5.8 lb/ft^2	278 n/m^2
Seating (Passengers)	26	26
Crew (Seats)	2	2
Maximum Cruise Speed	121 kts	62.2 m/sec
Service Ceiling[f]	12,500 ft	3.8 km
Cost	$2,370,000	-

[a] Sea level ISA

[b] Two G.E. CT58-140-2 engines

[c] Auxiliary tanks: 1635 lb (742 kg) additional

[d] Not including rotors

[e] Rotors turning

[f] Maximum Gross Weight

Source: Sikorsky Aircraft Division of United Aircraft Corporation
Janes, All the World's Aircraft, 1971-1972

PARAMETER NAME	UNITS	VALUE
MAX T.O. WT	LBS	19000.0000000000000
ALT MAX T.O. WT	LBS	19000.0000000000000
OP WT EMPTY	LBS	12860.0000000000000
MAX PAX CAPY	NO	30.0000000000000
MAX FUEL CAPY	GAL	654.0000000000000
NOM CLIMB SPEED CONST	KTS	61.0000000000000
NOM CLIMB SPEED COF1	KTS/FT	.0000000000000
NOM CLIMB SPEED COF2	KTS/LB	.0000000000000
ALT CLIMB SPEED CONST	KTS	61.0000000000000
ALT CLIMB SPEED COF1	KTS/FT	.0000000000000
ALT CLIMB SPEED COF2	KTS/LB	.0000000000000
NOM CRUISE SPEED CONST	KTS	109.0000000000000
NOM CRUISE SPEED COF1	KTS/FT	.0000000000000
NOM CRUISE SPEED COF2	KTS/LB	.0000000000000
ALT CRUISE SPEED CONST	KTS	80.0000000000000
ALT CRUISE SPEED COF1	KTS/FT	.0000000000000
ALT CRUISE SPEED COF2	KTS/LB	.0000000000000
LOITER SPEED CONST	KTS	62.0000000000000
LOITER SPEED COF1	KTS/FT	.0010000000000
LOITER SPEED COF2	KTS/LB	.0000000000000
NOM R.O.C. CONST	FT/MIN	5100.0000000000000
NOM R.O.C. COF1	FT/MIN/FT	-.0300000000000
NOM R.O.C. COF2	FT/MIN/LB	-.2000000000000
ALT R.O.C. CONST	FT/MIN	5100.0000000000000
ALT R.O.C. COF1	FT/MIN/FT	-.0150000000000
ALT R.O.C. COF2	FT/MIN/LB	-.2000000000000
NOM RATE OF DESCENT	FT/MIN	500.0000000000000
ALT RATE OF DESCENT	FT/MIN	1000.0000000000000
IDLE/TAXI FUEL CONST	LBS/MIN	5.0000000000000
IDLE/TAXI FUEL COF	LBS/MIN/FT	.0000000000000
NOM T.O. FUEL CONST	LB/MIN	12.6600000000000
NOM T.O. FUEL COF1	LB/MIN/FT	.0000756000000
NOM T.O. FUEL COF2	LB/MIN/LB	.0007319000000
ALT T.O. FUEL CONST	LB/MIN	12.6600000000000
ALT T.O. FUEL COF1	LB/MIN/FT	.0000756000000
ALT T.O. FUEL COF2	LB/MIN/LB	.0007319000000
NOM CLIMB FUEL CONST	LBS/MIN	24.7250000000000
NOM CLIMB FUEL COF1	LBS/MIN/FT	.0010250000000
NOM CLIMB FUEL COF2	LBS/MIN/LB	.0000000000000
ALT CLIMB FUEL CONST	LB/MIN	24.7250000000000

PARAMETER NAME	UNITS	VALUE
ALT CLIMB FUEL COF1	LB/MIN/FT	-.00102500000500
ALT CLIMB FUEL COF2	LB/MIN/LB	.00000000000500
NOM CRUISE FUEL CONST	LBS/MIN	4.47150800000000
NOM CRUISE FUEL COF1	LBS/MIN/FT	-.00017410000000
NOM CRUISE FUEL COF2	LBS/MIN/LB	.00052680000000
ALT CRUISE FUEL CONST	LBS/MIN	4.47150800000000
ALT CRUISE FUEL COF1	LBS/MIN/FT	-.00017410000500
ALT CRUISE FUEL COF2	LBS/MIN/LB	.00052680000500
HOVER FUEL CONST	LBS/MIN	-.25000000000000
HOVER FUEL COF1	LBS/MIN/FT	-.00006000000000
HOVER FUEL COF2	LBS/MIN/LB	-.00125000000000
LOITER FUEL CONST	LBS/MIN	-.15000000000000
LOITER FUEL COF1	LBS/MIN/FT	-.00016000000000
LOITER FUEL COF2	LBS/MIN/LB	.00075000000000
COST AIRCRAFT NEW	DOLLARS	2370000.0000000000000
COST AUX EQUIP	DOLLARS	20525.0000000000000
INS PREMIUM	PERCENT/YR	8.0000000000000
SALARY-CREW	DOL/YR EA	20000.0000000000000
MAINT LABOR	HR/FLT HR	9.0000000000000
MAINT PARTS	DOL/FLT HR	150.0000000000000
NOM FLIGHT CREW	NO	2.0000000000000
TYPE FUEL (AVGAS=0)	(JP=1)	1.0000000000000
COST FUEL	DOL/GAL	.5000000000000
COST LUBRICANTS	DOL/HR	1.0000000000000
RES FUEL NORMAL CRUISE?	YES=1:NO=0	1.0000000000000
FUEL EST FACTOR	N/A	1.0300000000000
SER CEILING CONST	FT	12000.0000000000000
SER CEILING COF	FT/LB	.0000000000000
BREAK ALT HI ALT CRUISE	FT	13000.0000000000000
HI ALT CRUISE CONST	KTS	.0000000000000
HI ALT CRUISE COF1	KTS/FT	.0000000000000
HI ALT CRUISE COF2	KTS/LB	.0000000000000
HI ALT FUEL CONST	LBS/MIN/LB	.0000000000000
HI ALT FUEL COF1	LBS/MIN/FT	.0000000000000
HI ALT FUEL COF2	LBS/MIN/LB	.0000000000000

Table 4-10. Sikorsky S-61 Helicopter Definition Parametric Values

5. MISSION ANALYSIS

A. GENERAL

In this section, the various missions examined in detail are described, and the results of their analyses are discussed.

This section is divided into five basic parts. First, a nominal mission is analyzed to provide general operational and economic parameters. Next, the offshore oil support mission, possibly the most significant mission of all those examined, is analyzed to provide specific results. The fire control mission is examined next in two aspects, those missions relating to the fixed wing "aerial tanker" and those performed by the helicopter. The results of these two analyses are significant to future advanced concept applications. The fourth mission studied is the personnel transport mission, particularly, the transportation of corporate executives. Next, a humanitarian mission is synthesized to examine the performance of the advanced concepts in the disaster relief role.

A full range of missions were examined for application of the advanced concepts from an initial list of missions compiled from the Helicopter Association of America (HAA) Directory of Members. This document lists 25 flying missions currently being performed by their members. While this may not be an exhaustive mission list, it is believed to be comprehensive enough to contain all the most likely missions, and certainly all those that would constitute the major markets for the application of the advanced concepts under study.

In consultation with NASA Ames Research Center's project management, an agreement was reached on the subset of the HAA mission list which appeared to be desirable for the analysis of this study. Those missions selected will be discussed in detail. The remaining missions fell into two classifications: those that appeared to be clearly inapplicable to the advanced concepts, and those that could be applicable under special cases. Table 5-1 shows the 25 missions considered with their classification, or disposition.

Table 5-1. Helicopter Missions Considered for Analysis

	Mission Name	Application Study	Application None	Application Possible	Remarks
1.	Agriculture			x	Discussed
2.	Air Carrier (FAR 127)			x	Not in Study Scope
3.	Air Taxi			x	Under Executive
4.	Ambulance			x	Under Humanitarian
5.	Bank Support			x	Under Executive
6.	Air Commuter			x	Not in Study Scope
7.	Construction				Not Considered
8.	Corporate	x			Under Executive
9.	Executive	x			
10.	Exploration			x	Under Offshore Oil
11.	External Load			x	Not Considered
12.	Fire Control	x			
13.	Forestry			x	See Fire Control
14.	Government			x	Under Executive
15.	Herding Livestock		x		
16.	Herding Wildlife		x		
17.	Law Enforcement			x	Discussed
18.	Logging			x	Not Considered
19.	Offshore Oil Support	x			
20.	Patrol			x	Law Enforcement
21.	Photography			x	Discussed
22.	Training			x	Not Considered
23.	Pollution Monitoring			x	Discussed
24.	Sightseeing		x		
25.	Traffic Reporting		x		

Source: Helicopter Association of America

From Table 5-1, it may be seen that only four missions of the 25 were eliminated as being of little or no interest for application to the advanced concepts. These missions were eliminated because their requirements could best be met with a small, inexpensive helicopter. Thus, the large machines of this study were immediately ruled out as being applicable to these missions.

The air carrier (FAR 127) and commuter missions are possibly good missions for these aircraft under special market conditions. However, the study of these special conditions were considered by NASA Ames Research Center as beyond the scope of this study because these two missions require extensive demand analysis of the markets they serve.

The agriculture mission (crop dusting and spraying) is generally more applicable to smaller helicopters which currently perform this mission both economically and effectively. The long-range, high-speed, heavy-load capabilities of the new concepts studied would, under most circumstances, be wasted in the agriculture mission. However, the study aircraft may find a role under special conditions, such as spraying large forest areas, remotely located from bases of supply. Therefore, this special agriculture mission, combined with the forestry mission, is a possible application for insect control, weed control, seeding, and fertilizing. This mission represents a small portion of both the agriculture and forestry uses of aircraft, and is not felt to be of such significance as to constitute a distinct and recognizable market for such a machine.

The HAA differentiates the "Corporate" and "Executive" missions on the basis of whether the aircraft is owned by the corporation (Corporate), whose executives are being transported, or whether the aircraft is operated for hire (Executive). This distinction is not made in this study. Additionally, the air taxi is clearly considered akin to the personnel transport mission, as analyzed here, and the ambulance and bank support missions (ambulance missions are also covered by the analysis of the humanitarian mission -- not listed by the HAA). The economic factors, which make the aircraft acceptable to the personnel transport missions, are applicable to these

three as well. The government mission is difficult to classify since it could conceivably be any of the other 24 missions when performed for the government. Here, it was assumed as a government executive mission and, therefore, included as a part of the transport study analysis.

While construction, logging, and external load missions are extremely appropriate missions for the advanced helicopter, they appear to be inappropriate for the lift fan aircraft in particular, and quite possibly so for the tilt rotor. If medium and heavy lift helicopters similar to the advanced helicopters of this study were not expected to be available in the future, then it would be of interest to look, at least, at the practicality of using a tilt rotor in these external load missions. However, during initial conferences to assess mission applicability, NASA Ames Research Center and The Aerospace Corporation felt that the study effort should be directed toward missions with better payoffs than those requiring much hovering, being generally of short range, and having external loads. It was assumed that, regardless of the development of civil lift fan aircraft or the tilt rotors, the advanced helicopters (or an aircraft of similar capabilities) will be on the scene in the 1980-1990 period. Therefore, the relative showing of these three aircraft in hovering-type missions should have no effect on the advanced helicopter development, and it is doubtful that any significant markets for the other two concepts will occur in this area.

Exploration missions encompass a variety of purposes, including remote camp support via transporting men, supplies, and equipment, and additional support to such oil drilling exploration in remote sites via external loads such as drilling rigs. The external load missions were conceded to the helicopters. Thus, appropriate for the lift-fan and tilt-rotor, the only exploratory missions are those involving personnel or materiel transport to offshore oil exploration sites or to other sites in remote inaccessible areas. This report examines the utility of the subject aircraft for the offshore oil mission, which is considered representative of exploratory missions in general.

The following missions were also eliminated from consideration for the reasons stated. Law enforcement, patrol, pollution monitoring, and photography missions are generally more practically accomplished in smaller, slower aircraft. There are some special cases where fast, long-range vehicles may be of benefit, but not in numbers significant to affect the size of a market analysis. Border patrol missions could conceivably be enhanced by a few aircraft which would be able to pursue a commercial jet and, yet, could also land on small heliport-sized spaces to support ground parties. For the small portion of time that an aircraft with the capabilities of the advanced concepts could be gainfully employed in a photographic mission, it would appear to be more practical to lease the aircraft than to own it.

The training mission is the only one not yet discussed. It is felt that a significant market would not exist specifically for training on these aircraft. The operators purchasing and using the aircraft for the major missions will, of necessity, expend some portion of their flight time in training and maintaining the proficiency of their crews. Instead of adding to the market, this training activity will tend to increase the overhead operating expenses for the major mission classifications. (This cost, incidently, has not been included in the operating costs shown in the analyses.)

All missions examined were considered as being conducted under visual flight rules (VFR), and the fuel reserves for these flights were established for 45 minutes of flying at 10,000 feet (3,048 m) at maximum range cruise power. Range performance must necessarily be adjusted by reducing the range by approximately 100 n.m. (185 km) if missions are generally operated under instrument flight rules (IFR) in order to account for fuel when flying to an alternate airport. All analyses assume zero wind. Actual operations generally incur a range penalty because of wind, especially, radius of action missions, such as the offshore oil support mission.

B. AIRCRAFT NOMINAL PERFORMANCE

The nominal performance (operational and economics), as used in this report, refers in general to the payload, time, and cost parameters as a function of operating range. These three parameters were calculated for the three advanced concepts and the two contemporary designs used for comparisons. These parameters plus derived functions are presented in this section. Calculations were based upon a simple mission consisting of load, warm-up,taxi out (where necessary), takeoff, en route (climb, cruise, and descent), and landing. The aircraft was assumed to always take off at maximum gross weight. Cruise was based upon the maximum cruise speed. The results of these nominal mission flights are shown graphically in Figure 5-1, 5-2, and ~~5-6-a~~ 5-3a.

In Figure 5-1, it may be observed that the lift fan aircraft in the STOL mode of operation has the greatest payload/range capability. When employed as a VTOL, the lift fan aircraft is somewhat more limited in payload than the other advanced concepts, but with comparable range. The break points in the curves (at payloads of approximately 5000-6000 lb (2268-2721 kg)) represent the range beyond which payload weight cannot be traded off for additional fuel. That is, these ranges represent the maximum payloads with maximum fuel. Additional range results from off-loading payload and, thereby, obtaining additional range, simply, because the aircraft is lighter. In the case of the advanced concepts, the knee of the curves represents their design ranges. The lift fan aircraft in the VTOL mode has no break in its payload versus range curve since the fuel capacity in this mode is sufficient to absorb any off-loaded cargo.

For this nominal mission, additional range is possible by using the maximum range cruise speed with attendant penalties on time and operating costs. It should be noted that the range of the Sikorsky S-61 is limited to approximately 50 miles (93 km) with 5000 lb (2268 kg) payload, the equivalent of 26 passengers, its maximum passenger configuration (S-61N).

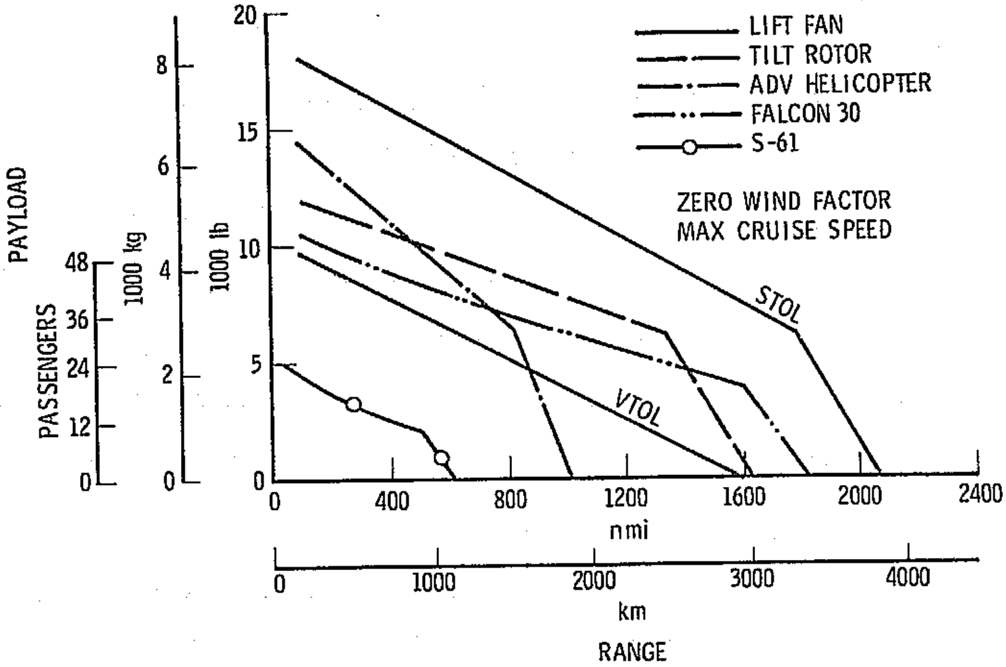

Figure 5-1. Nominal Range vs Payload Performance

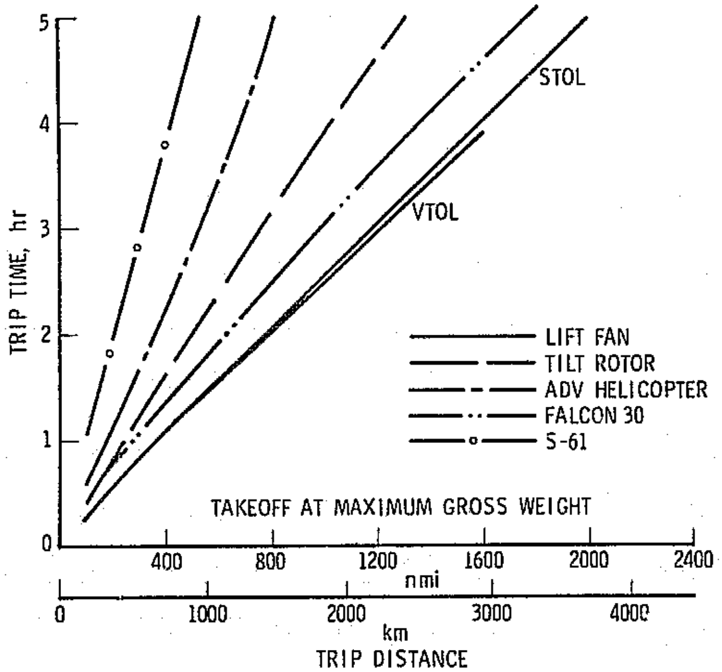

Figure 5-2. Trip Time as a Function of Range

The missions at the lower ranges could allow large payloads to be carried within the aircraft's maximum takeoff weights. While this may appear not to be practical, it can be shown that the lift fan STOL, the aircraft with the greatest payload capability, can carry an 18000 lb (8165 kg) cargo whose density is equal to that of water in roughly one-third of its fuselage volume.

Figure 5-2 indicates the relative speeds of the various aircraft by showing their times to specific ranges. In this figure, time was calculated from the start of warmup through the landing phase. The trip time associated with access and distribution segments at each end of a trip are not considered here (these are discussed as appropriate to specific missions in later sections). Trip flying time was calculated by assuming maximum gross weight at takeoff. Flights at ranges less than maximum ranges (using less than maximum takeoff weight) may be reached in a slightly different time period since some of the aircraft cruise speeds are sensitive to gross weight conditions. Also at lighter weights and at the shorter ranges, the aircraft would tend to climb to higher elevations, affecting the total flying time and fuel consumption by changing the climb and descent segments as well as the length of the cruise segment and its speed which is generally sensitive to altitude.

Figure 5-3a combines the range versus payload information of Figure 5-1 with the costs associated with operations. Generally, the hourly costs are inversely related to the range since the higher costs associated with the slower segments (takeoff, climb, and descent) are spread over a greater time span as the range increases. Since fuel required for increased range requires a reduction in the payload carried (for flights with takeoff at maximum gross weight), trip efficiency tends to decrease with range. All the curves tend to bend up sharply at their extreme ranges since at this point useful load is, indeed, small. From this figure, it may be seen that the lift fan (STOL) and the Falcon 30 have approximately the same efficiency in terms of costs per unit payload distance. However, when operated in the VTOL mode, the lift fan is penalized by a reduction in takeoff gross weight of approximately 5 tons (4536 kg) with little reduction in operating costs,

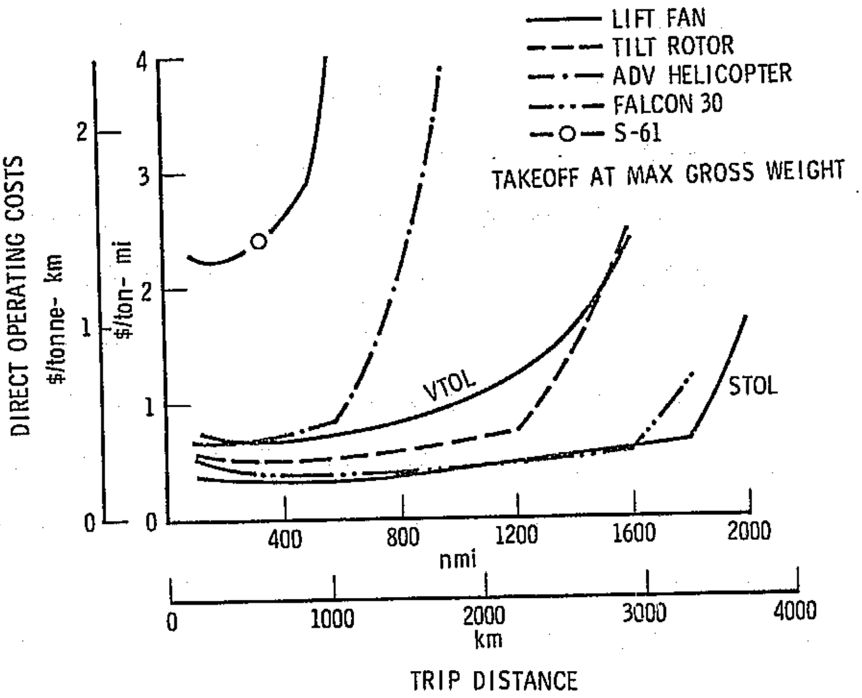

Figure 5-3a. Costs Per Available Unit Payload Distance - Maximum Payload

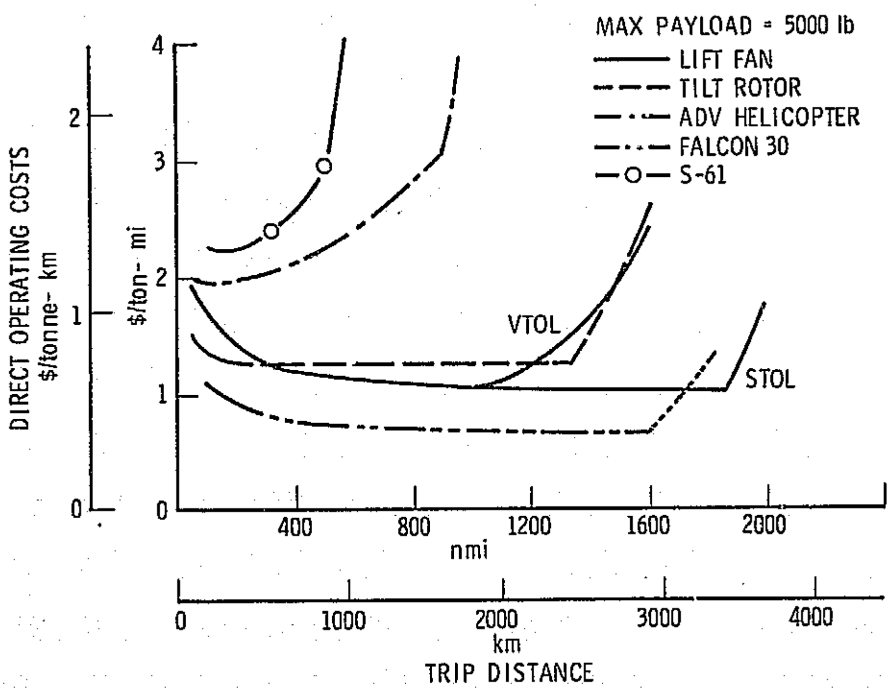

Figure 5-3b. Costs Per Available Unit Payload Distance - Maximum Payload 5000 lb (2268 kg)

thereby greatly increasing its ton mile costs as shown. The tilt rotor is shown to fall between the lift fan, operating in its two modes. The advanced helicopter is only cost competitive in the shorter ranges (where the higher costs associated with the takeoff and landing of the other two advanced concepts are more pronounced). Even so, it may be seen that the advanced helicopter performance is an improvement over the contemporary S-61.

The most efficient ranges for employment of any of the concepts lie in the range to the left of the points where the costs begin to rise sharply, such as 1600 n.m. (2963 km) for the lift fan (STOL) and the Falcon 30, and 1000 n.m. (1852 km) for the tilt rotor.

The costs shown are for takeoff at maximum gross weights, computed on the basis of flying 800 hours per year. It is recognized that lighter weight takeoffs will operate slightly less expensively over the same range than fully loaded aircraft, but the savings in hourly costs are generally not large and the penalty for not utilizing the aircraft's full capability is great. This may be seen in Figure 5-3b where the maximum payload is limited to 5000 lb (2268 kg).

Figure 5-4 shows costs per trip unit distance of a fully loaded aircraft as a function of trip distance. These calculations are also based upon a utilization of 800 hours per year. Short trips reflect the proportionately higher cost penalties associated with the takeoff, climb, landing, and ground operations. These costs are spread over a greater distance at the longer ranges and yield lower unit distance costs beyond 400 n.m. (741 km), for the most part. The advanced helicopter shows an optimum cost per trip at approximately 600 n.m. (1111 km). It can be shown that except for the advanced helicopter these values are relatively insensitive to takeoff weight. The advanced helicopter, however, exhibits a notable speed decrease with decreasing weight which results in costs generally being above \$5/trip-mile (\$2.50/trip km) with a payload of 5000 lb (2268 kg).

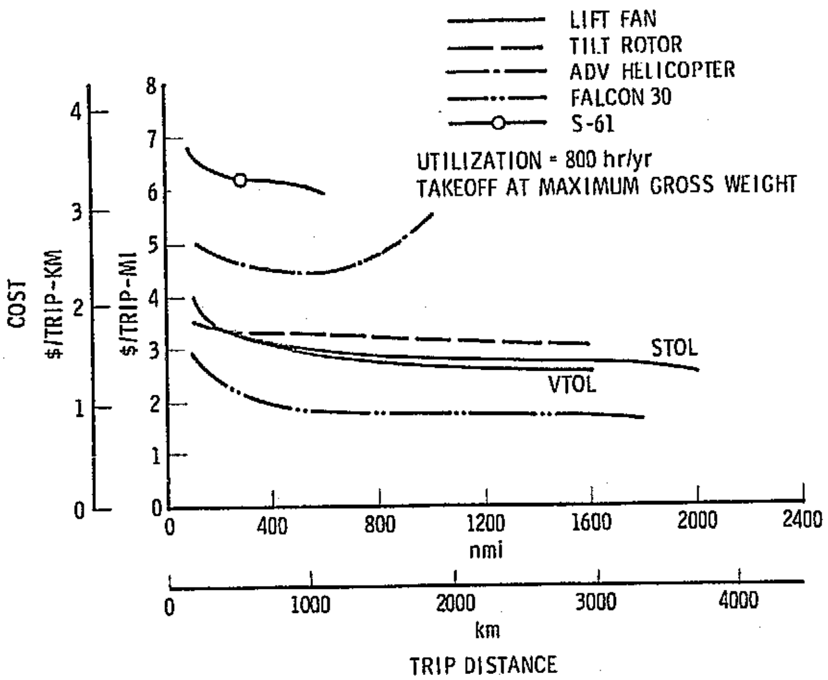

Figure 5-4. Costs Per Trip Unit Distance

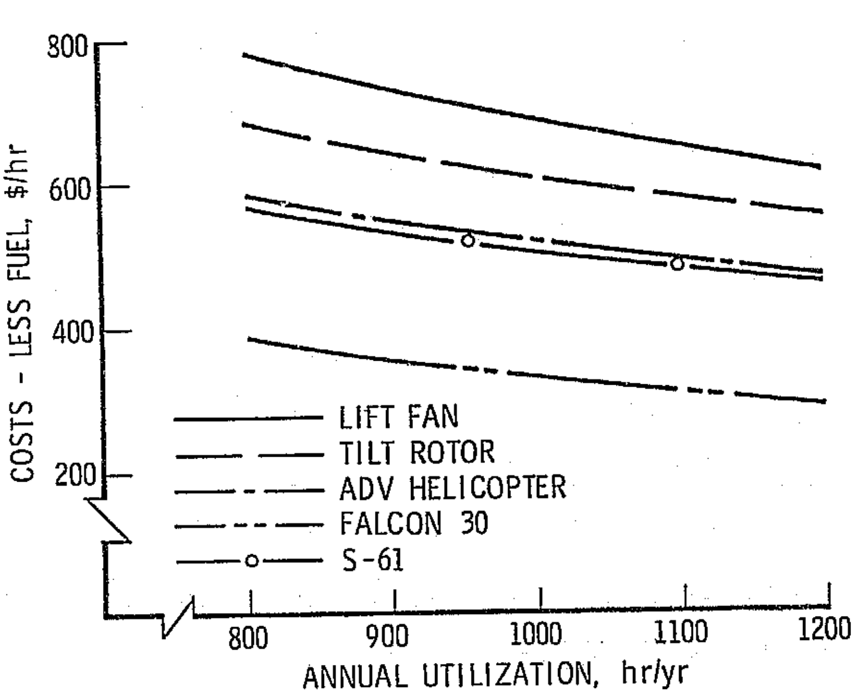

Figure 5-5. Operating Costs (Less Fuel) as a Function of Utilization

Annual utilization is a major determinant of the hourly costs when computed as an average over a year. Many of the costs are fixed and must be spread over a year's total flying time. Figure 5 - 5 is a representation of operating costs for the range of annual flying time from 800 hours to 1200 hours. For any given utilization, the cost per hour is sensitive to the average trip length since fuel may contribute up to 30 percent of the hourly costs, depending on the range and aircraft type. Therefore, Figure 5-5 shows the sum of all cost elements, with the exception of fuel. Fuel costs as a function of range are provided in Figure 5-6a. Here, it may be seen that all aircraft trip fuel costs are reasonably well grouped for the short-range flights. The fuel costs for the lift fan are only modestly greater than the advanced helicopter at the lower ranges. The hourly fuel costs are shown for all aircraft in Figure 5-6b. Even though the lift fan aircraft's total hourly costs may seem relatively high, it must be remembered that, because of its speed, it can accomplish the same mission in a much shorter time than the other aircraft, and with overall comparable mission costs. Also, the STOL lift fan has a much larger payload/range envelope than the other concepts (Fig. 5-1). It is for these reasons that the lift fan may be found close to the other aircraft in economic performance in Figures 5-3 and 5-4.

Since the oil embargo of 1974, reasonable concern has been paid to the fuel efficiency of the various modes of transportation. For air travel, fuel expenditures must necessarily be justified on the basis of time savings and the recognition that, in many situations, flying is the only practical transportation mode to many places in the world. In addition, some of the places require an aircraft with VTOL capability. Therefore, it is of interest to examine the aircraft analyzed in this study in terms of their relative fuel economies as shown in Figure 5-7 where both maximum payload and payloads limited to 5000 lb (2268 kg) are presented. It should be noted that all of the advanced concepts are more fuel efficient than the relatively older VTOL technology represented by the S-61. As a STOL at maximum payload, the lift fan aircraft is about as efficient as the Falcon 30, a conventional takeoff and landing aircraft (CTOL). Both of the fixed wing

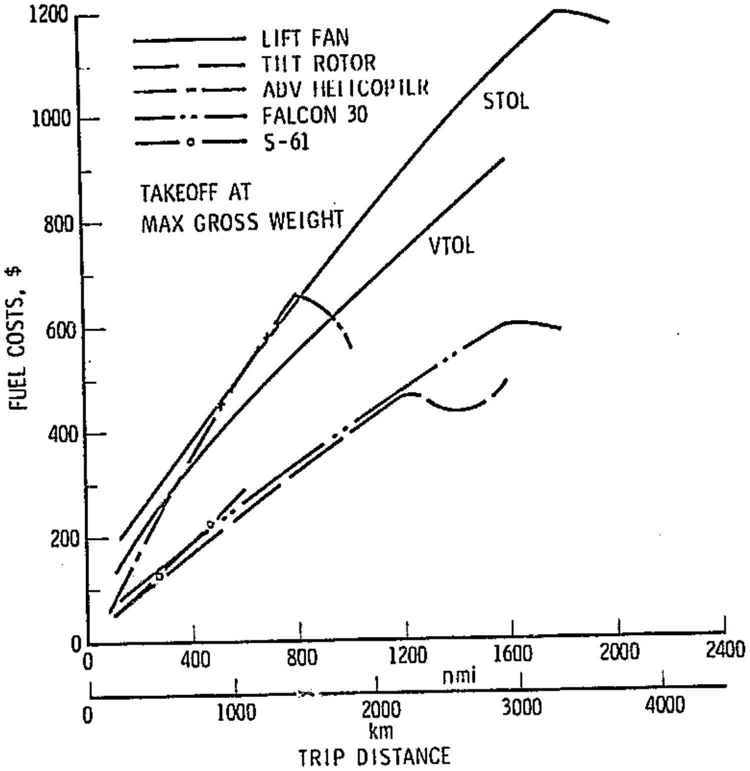

Figure 5-6a. Fuel Trip Costs As a Function of Range

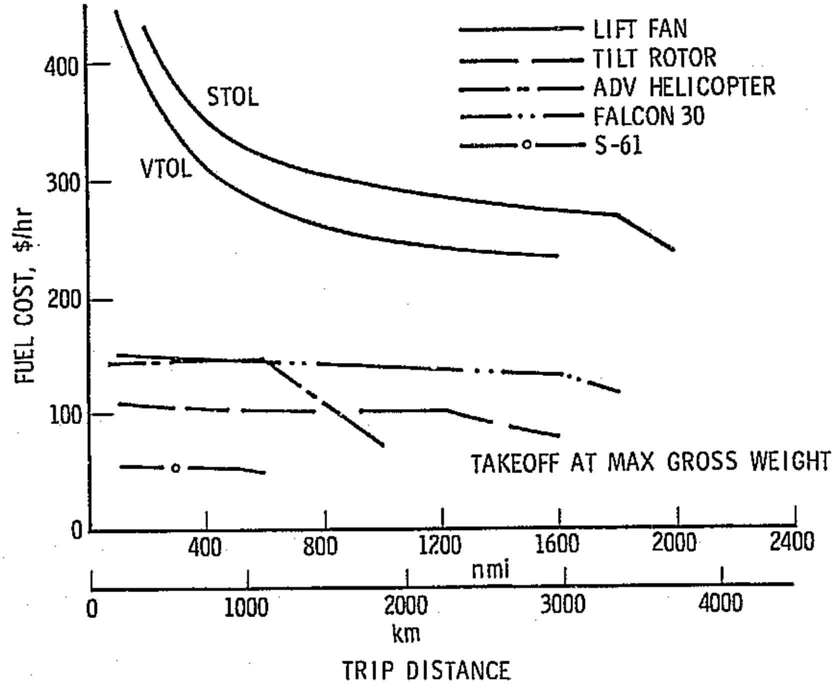

Figure 5-6b. Fuel Hourly Costs as a Function of Range

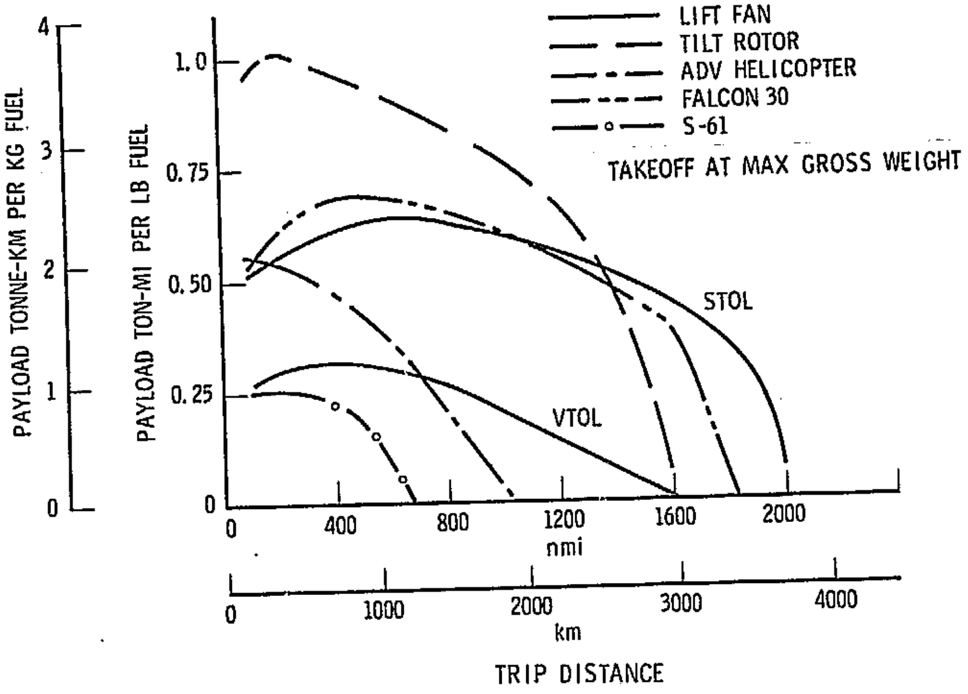

Figure 5-7a. Aircraft Relative Fuel Efficiency - Maximum Payload

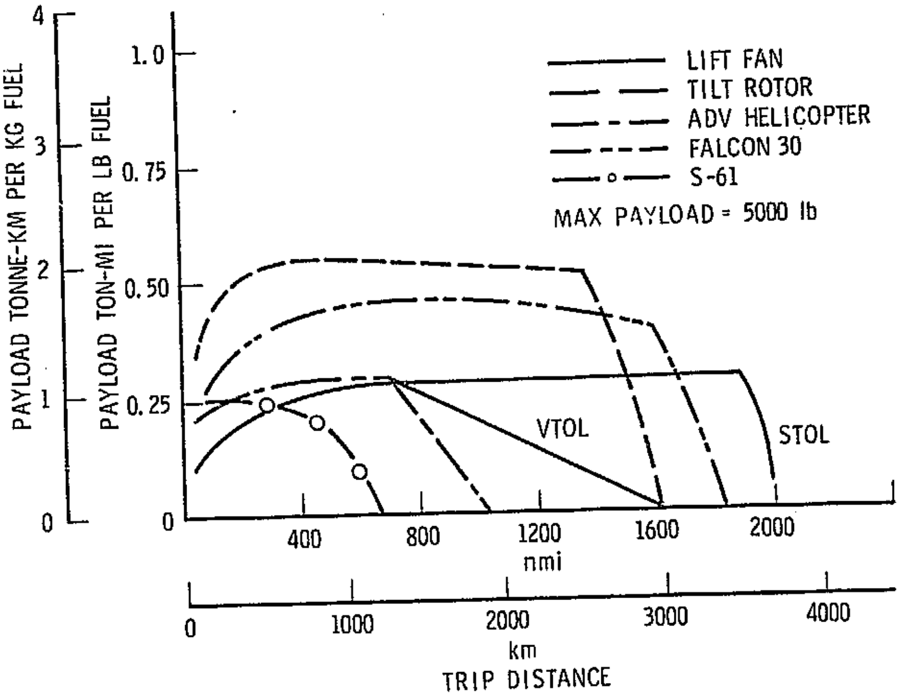

Figure 5-7b. Aircraft Relative Fuel Efficiency - Maximum Payload 5000 lb (2268 kg)

advanced concept aircraft, because their cruise employs aerodynamic lift, instead of powered lift as used by the advanced helicopter, are considerably more efficient than the advanced helicopter at ranges over 400 n.m. (741 km). The tilt rotor, because of its turboprop configuration in cruise, is the most efficient of all.

Figure 5-7b. shows the effects at shorter ranges on fuel efficiency of limiting the payload. The lift fan is noticeably penalized in this case.

These generalized curves may be used to provide reasonable estimates of the economic performance for missions not analyzed in detail in this report. Allowances for landings en route may be made by considering multistop missions as a number of shorter missions. Total costs can be estimated by entering Figure 5-5 at the appropriate annual utilization rate to get the operating costs less fuel costs. To this must be added the hourly fuel costs for the mission average range of Figure 5-6b.

Figure 5-2 may be used to estimate operational ranges while Figure 5-3 provides flying time estimates. To the flying time of Figure 5-3 must be added any appropriate delay times associated with the mission and the particular aircraft being used.

At the outset of this study, it was recognized that performance figures tend to be controversial and that economic performance is more so than operational performance. This is true of existing aircraft and certainly more appropriate to aircraft to be built, flown, and maintained in the future. Operational performance is highly dependent upon the operator's policies, and operating costs also depend greatly on how the aircraft is used (or abused) in operations and how the maintenance is performed. Quite frequently, manufacturers estimate operating costs by using assumptions which may vary widely from the actual conditions under which typical operators must operate. Therefore, the cost numbers provided by this study are subject to some interpretation. They tend to be mainly conservative (on the high side) and, hopefully, reflect the situation more from the operator's viewpoint than that of a manufacturer. The attempt has been to establish the relative, if not the absolute, costs in order to provide some comparisons that would indicate economic feasibility of the concepts under consideration.

Specific missions are analyzed in sections which follow. Payload versus range curves and operating costs per unit payload distance are not repeated, except as may be required because of mission peculiarities. The curves presented here are considered to be reasonably representative of the other missions. However, in the following sections other parameters are discussed which are mission peculiar and which provide unique measures of mission performance.

C. THE OFFSHORE OIL SUPPORT MISSION

This mission is typified by the regular transportation of drilling and production crews to and from offshore oil platforms from on-shore bases in relatively large helicopters[1] (sized for 15 or more passengers). Additionally, smaller groups may be transported on an irregular basis. Most of this transportation occurs on regularly scheduled flights to rotate the crews approximately every week. Currently, the major requirement exists principally in the Gulf of Mexico (U. S.), in the North Sea, and in Southeastern Asia. A study of oil industry reports indicates that other areas may develop, where this type of transportation may be used in the future; for example, the U. S. Northeastern Atlantic area, and off the coast of California. Irregular transportation of inspection teams and quick-response transportation of trouble shooters may occur in any part of the world where offshore oil is produced, such as Southern California, the Persian Gulf, or Venezuela, in addition to the other locations mentioned above. These latter areas produce oil relatively close to shore, and, since personnel parties are small, small helicopters (of 6-8 passenger size) generally suffice for this work.

1. CURRENT OPERATIONS

Currently, the offshore oil support mission is usually performed by the Sikorsky S-61 and S-58T, Bell 205 and 212, and the Aerospatiale Puma. The size of the crews transported range from five men on small production platforms up to 100 men during construction work on drilling platforms.

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1 An up-to-date and comprehensive assessment of this mission is contained in reference (7).

Normally, crew sizes range from 10-40 men. Crew rotation varies somewhat around the world. In the United States, crews are rotated customarily every seven days, and in the North Sea it currently varies between 8-14 days, with a general trend towards the lower figure. The size of helicopters is sometimes limited by the size of the heliport at the platform. Other determinants are the desire to optimize trips and carry integral crews, plus the requirement to carry fuel for the round trip as well as reserves.

The round-trip distances are affected by a number of variables. Principal among these are shore base location, the location of oil deposits, slope of the continental shelf in the drilling area, drilling technology development, and the general condition of the weather and sea in the area.

Shore bases are located as close to the offshore drilling areas as practicable; however, these bases may be greater than minimum possible distances in order to optimize their locations to provide proper aircraft logistic and maintenance support (i. e., located close to civilization in less populated countries). This also tends to locate the operation's bases in areas where the oil workers can find housing for themselves and their families. Furthermore, it places the base where it is reasonably close to sources of supply for the oil operations.

Offshore oil deposits have been discovered in a variety of locations of the world. Principal producing areas in the United States are located along the Southern California Coast, and in the Gulf of Mexico from Texas to Florida. The North Sea from the British Isles to Scandinavia and to the Netherlands is a recently developing area for production, while the Persian Gulf and Lake Maracaibo in Venezuela have been in production for many years. Oil companies are currently engaged in offshore oil production and exploration in Southeast Asia from the Gulf of Siam, through the Java Sea, along the Shores of Malaysia and Indonesia, up through the Philippines. Other, lesser known areas, such as the west coast of Africa, Japan, and Australia, are under exploration and production in limited quantities.

A survey of the distance of current and probable future drilling in principal offshore oil production areas was conducted to establish a reasonable radius of action for such mission and to aid in the understanding of the future requirements for V/STOL aircraft. Table 5-2 summarizes the findings of this survey.

In summary, the offshore oil mission typifies the routine transportation, on a scheduled basis, of the workers to and from drilling and production oil platforms at 50 nm (93 km) or greater distances at sea, or in rough seas at lesser distances. Irregular missions are also performed at all distances for the purpose of inspection, repair, and emergency evacuation.

2. MISSION PARAMETERS

Data obtained from the survey of offshore oil-producing areas of the world, plus information from offshore helicopter operators, were combined to develop a typical mission profile. This mission profile provides the baseline from which the parametric studies were made. Figure 5-8 depicts the typical mission, and Table 5-3 provides the values assigned to the parameters. Those parameters, subject to variation during the mission analysis, are indicated.

The distance was varied from 50 nm (93 km) to the maximum operating range of each aircraft to perform the defined mission.

Passengers were varied as required to match the maximum capacity of the aircraft analyzed. Also, passengers were off-loaded as necessary to permit loading more fuel to accommodate the longer-range missions.

Cargo was assumed in all cases to be only baggage. A baggage allowance of 20 lb (9 kg) per passenger was used. Total baggage on any flight fluctuated directly with the number of passengers.

A minimum altitude of 1000 ft (305 m) was specified; however, no maximum altitude was established and, thus, the aircraft were permitted to climb to higher, more efficient altitudes, being limited only by their weight and ability to reach the higher altitudes as a function of range.

Table 5-2. Summary of Conditions Affecting V/STOL Operations in the World's Offshore Oil Production Areas

Production Area	Maximum Distance, nm (km)*	Conditions Affecting V/STOL Operations
Alaska	100 (185)	Lightly populated, severe weather conditions, environmental concerns regarding establishment of CTOL bases
Southern California	100 (185)	Densely populated, relatively sheltered water, few storms
Gulf of Mexico (U.S.)	300 (556)	Moderately populated, rough seas in winter, hurricanes prevalent
Gulf of Mexico (Mex.)	50 (93)	Moderately populated, good weather, few tropical storms
Venezuela/Trinidad	50 (93)	Moderately populated, protected waters
North Sea	250 (463)	Moderately populated, rough seas, several political jurisdictions
Persian Gulf	50 (93)	Moderately populated, good weather, protected water
Southeast Asia	300 (556)	Lightly populated, good weather, inhospitable terrain
Australia	100 (185)	Moderately populated, rough seas

*Nominal maximum distances for operations in the 1980's

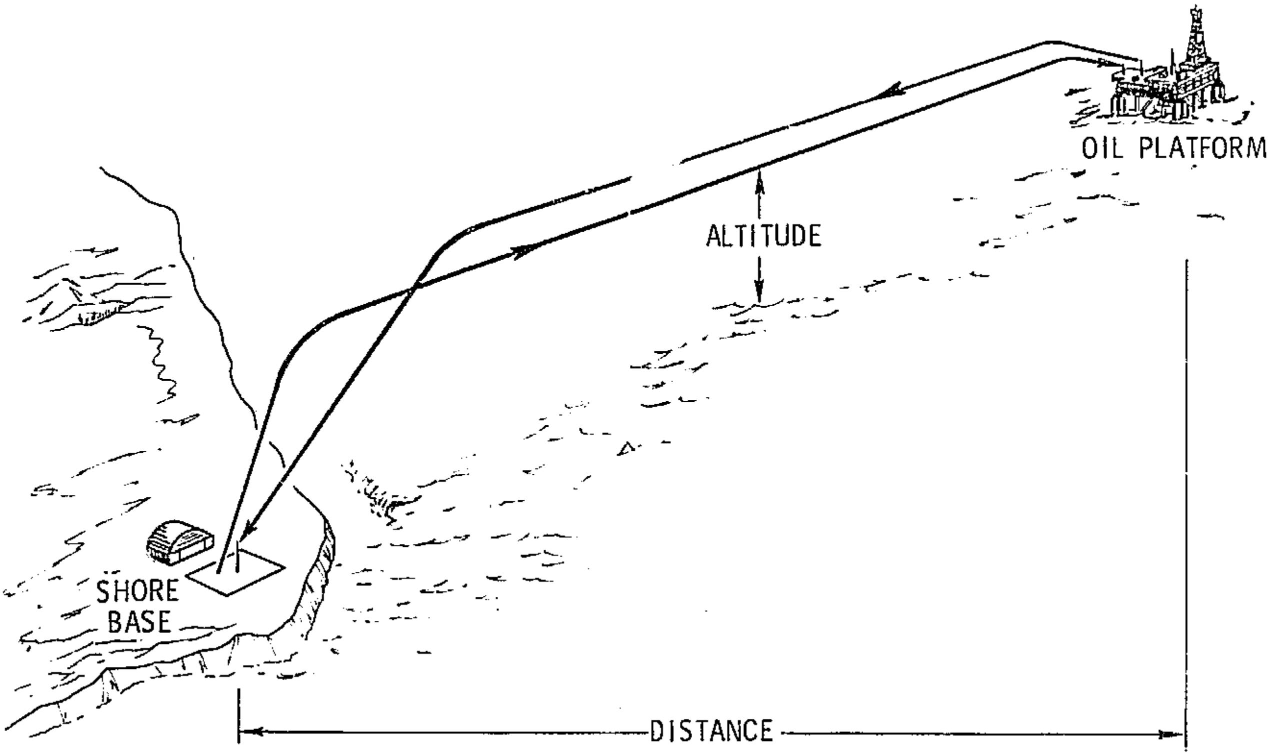


Figure 5-8. Typical Offshore Oil Mission Profile

Table 5-3. Offshore Oil Mission Parameters

Mission Segment	Time (min)	Distance (nm)	Passenger (No)	Cargo (lb)	Altitude (ft)	Remarks
Load	5	--	*	*	--	
Warmup	5	--	--	--	--	
Takeoff	1	--	--	--	0	
En Route	--	*	--	--	1000	Min. Altitude
Land	1	--	--	--	0	
Unload	2	--	*	*	--	
Load	5	--	*	*	--	
Takeoff	1	--	--	--	0	
En Route	--	*	--	--	1000	Min. Altitude
Land	1	--	--	--	0	
Unload	2	--	*	*	0	
Refuel	15	--	--	--	--	These impact number of missions per day possible.
Standby	30	--	--	--	--	

* Parametrically varied

3. MISSION ANALYSIS

The results of the offshore oil mission analysis are contained in Figures 5-9 through 5-12. The first of these figures indicates one of the most important parameters of the offshore oil mission: the tradeoff between payload (passengers, in this case) and range. Because of the difficulty associated with refueling on the drilling and production rigs, missions were generally defined as round trip requiring good payload versus range characteristics. Current offshore rigs are at the maximum range of such aircraft as the S-61, even in an off-loaded configuration. Figure 5-9 clearly shows the ability of these advanced concepts to operate in the expanding range requirements of the offshore oil industry.

The lift fan VTOL and the advanced helicopter are limited to a radius of approximately 300 nm (556 km) with a full passenger load. However, the lift fan STOL mode operation extends this radius to over 800 nm (1482 km). The tilt rotor, a VTOL, has an uncompromised radius of action of about 650 nm (1204 km).

All of the advanced concepts, except the lift fan VTOL, are operating at their "design load" points with full passenger loads; the trade-offs between passengers and range result simply from lightening advanced concept aircraft, thereby extending the range. The lift fan VTOL is constrained, on the other hand, in its takeoff weight. By eliminating passengers, it can take on more fuel, thus extending its range because of the extra amount of fuel.[1] For this reason, the slope of the passenger-versus-range tradeoff curve is different for the lift fan VTOL and the other advanced concepts. Provisions for auxiliary fuel in the other advanced concepts would result in a reduced slope to these curves, with an attendant extension of the range.

Figure 5-10 indicates the relative productivity of the concepts, and the maximum radius of action for each aircraft examined. The lift fan aircraft, by virtue of its speed, is the best aircraft, considering productivity. The only restriction on the lift fan STOL weight (aside from the maximum weight of 45,000 lb (20,412 kg) is that the aircraft

[1] This is also true for the S-61 which trades passengers for fuel up to 200 nm (370 km).

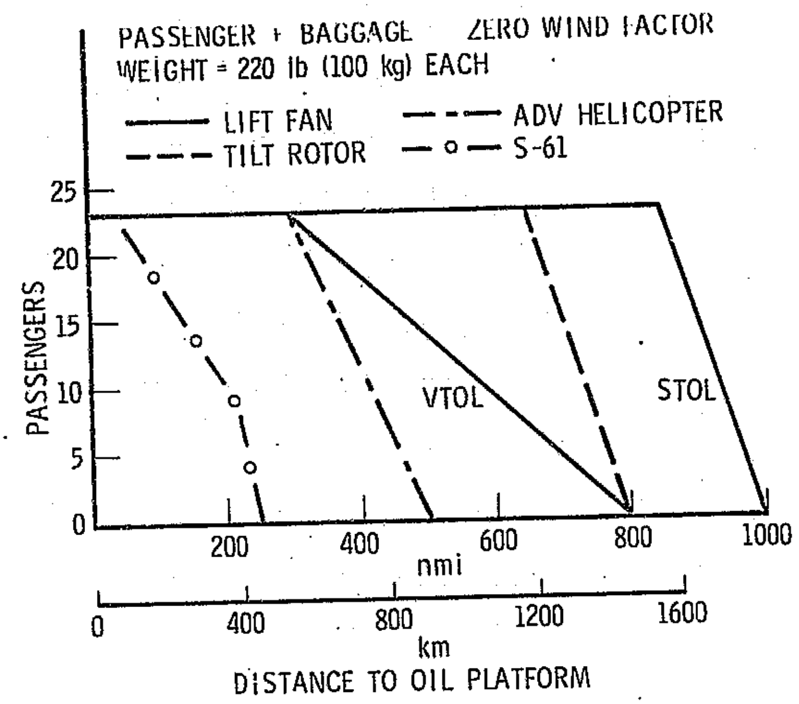


Figure 5-9. Relative Range Capabilities of Advanced Concepts in Offshore Oil Support Missions

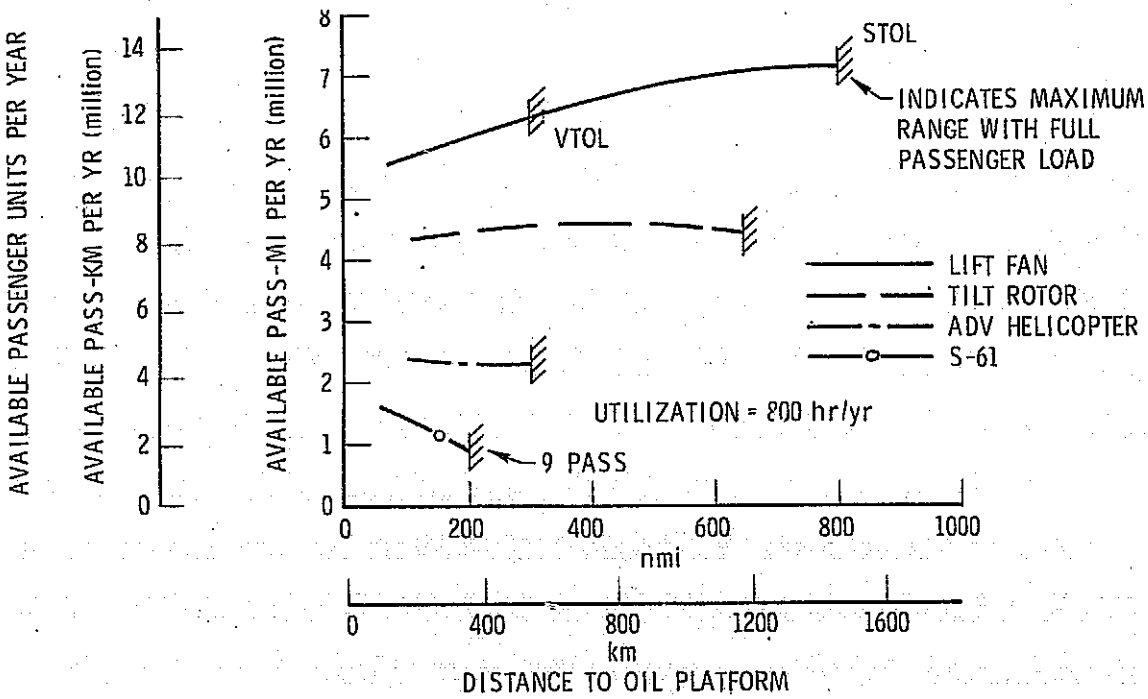


Figure 5-10. Aircraft Productivity in Offshore Oil Support Missions

must have burned off enough fuel upon reaching the oil rig to effect a safe vertical landing. Figure 5-11 shows the maximum allowable STOL takeoff weight as a function of range to the platform.

The tilt rotor productivity, while not as good as the lift fan aircraft's, is very good compared to the contemporary S-61, and considerably better than the advanced helicopter's. Also, the tilt rotor's radius of action is sufficient to cover all United States and North Sea operations envisioned, and many of those in Southeast Asia. The range may be extended even more if the initial takeoff is made as a STOL (not considered in this study).

The advanced helicopter exhibits radius of action capabilities satisfactory for typical United States and North Sea operations, and its productivity is generally twice that of current helicopters at the long range.

Cost of operations are exhibited in Figure 5-12. Here, the hourly cost variations with utilization are shown as developed from trips to a platform at 100 nm (185 km) from shore (200 nm (370 km) round trip). Utilization of 1000 hours or more per year is common among operators serving this mission. It can be seen that the lift fan aircraft is almost twice as expensive on an hourly basis as the S-61, but the very large productivity of the lift fan more than offsets this. The other two advanced concepts are only moderately more expensive than the S-61 on an hourly basis; but in considering their productivity, this is not a significant factor if the aircraft are employed efficiently.

Figure 5-13 illustrates the effect of productivity on the cost of operation. Here, it can be seen that the lift fan aircraft, the most expensive on the basis of dollars per hour, shows the lowest cost when considering the cost of available seat miles. Since the available seats on the advanced concepts are constant for the ranges shown, the costs for these aircraft are reasonably flat (except for the lift fan STOL). The S-61, on the other hand, must off-load passengers to achieve its greatest range, thereby reducing its available seats and increasing its costs. Of course, the cost per actual passenger mile is inversely proportional to the load factor; therefore the cost will increase if the aircraft is less than full.

All the advanced concepts are better for the offshore mission than currently used modes, regardless of range. The lift fan STOL is competitive with the tilt rotor (VTOL) at ranges beyond 300 miles (one way).

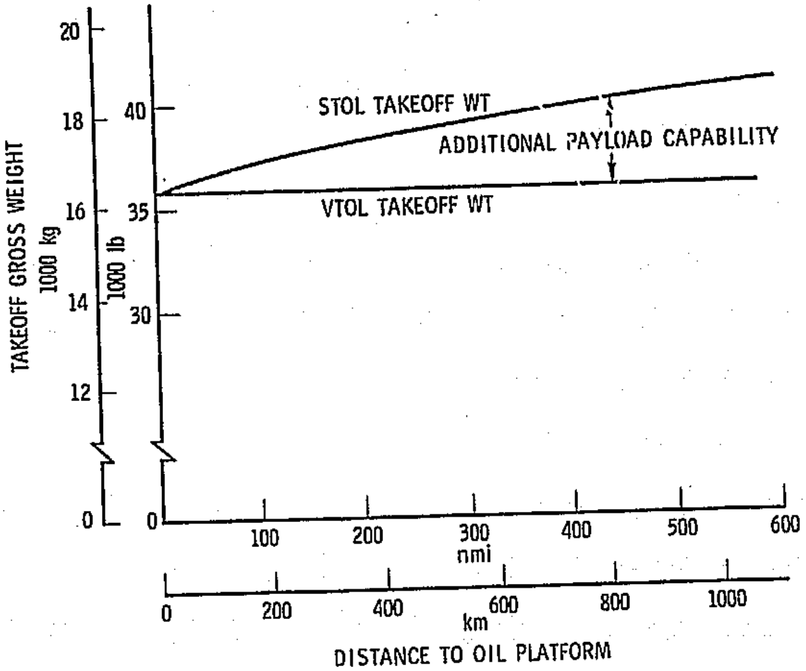


Figure 5-11. Lift Fan Maximum STO Takeoff Weight vs Range

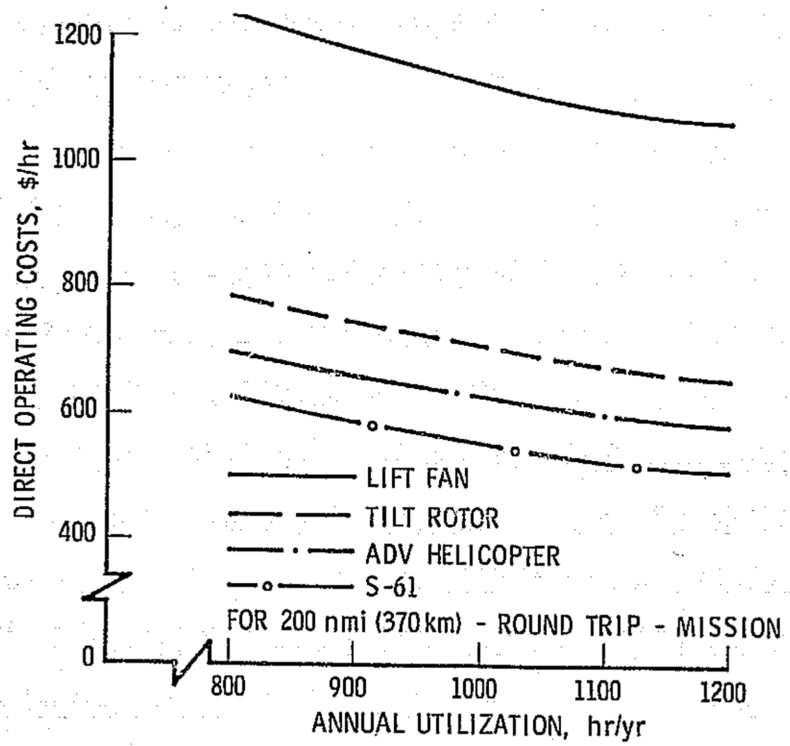


Figure 5-12. Offshore Oil Mission Hourly Costs as a Function of Utilization

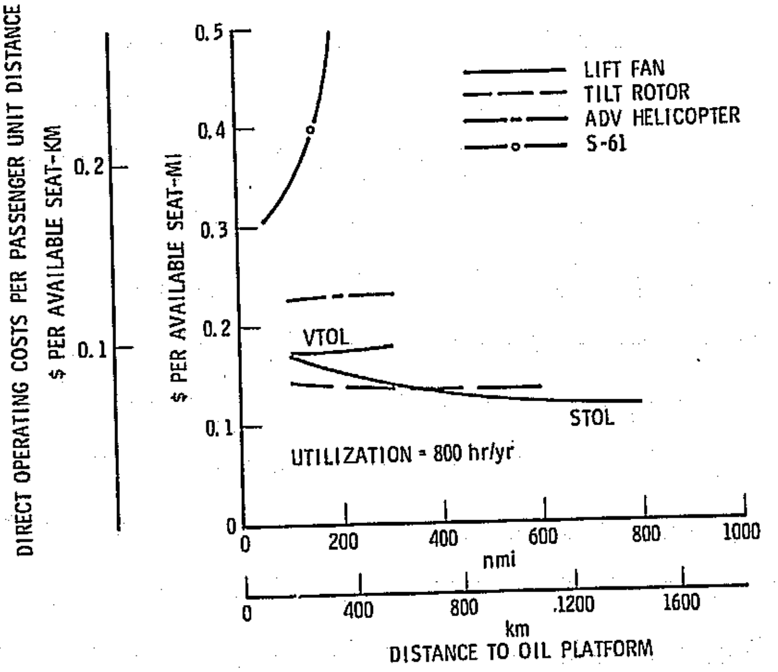


Figure 5-13. Direct Operating Costs in Offshore Oil Support Missions as a Function of Range

D. FOREST FIRE SUPPORT MISSIONS

The U.S. Forestry Service and the State of California use fixed-wing and helicopter aircraft in a number of forestry missions. Some of these are similar in nature to other uses of these machines; for example, personnel transport of fire crews is in many ways like the transport of construction crews, except in case of a fire, time is a more critical factor. Or, spraying, reseeding, and fertilizing in the forest is similar to other agricultural uses, except for the altitudes encountered, and possibly the distances to be flown and the acreage to be covered. The fire control missions, the dropping of water or special chemical retardants, on the other hand, is a unique use of aircraft, and in this study is considered for special analysis.

Aerial fire control may be effectively employed in any area where fire danger is high, areas are relatively inaccessible by other means, and large areas of forest and watershed lands are considered of sufficient value to warrant the cost. The United States, Canada, Spain, and Italy are currently the principal users of this method of fire control.

1. CURRENT OPERATIONS

Figure 5-14 shows the forestry regions of the United States and their involvement in aerial fire control. The statistics shown for 1974 indicate the percent of total retardants dropped by the United States Forest Service (USFS) in each region and the total hours flown by fixed-wing and helicopter aircraft in fire control missions. These flight hours are those flown by USFS owned or contract aircraft (the major contributor to these missions) and do not include any hours flown by state and/or county fire units.[1]

In addition, the California Department of Forestry flew 8236 hours in 1974 and dropped an estimated 3.4 million gallons of retardants and water.

[1] California and Los Angeles County are the only two other agencies (beside the USFS) in the U.S. which fly any significant number of hours in forest fire missions.

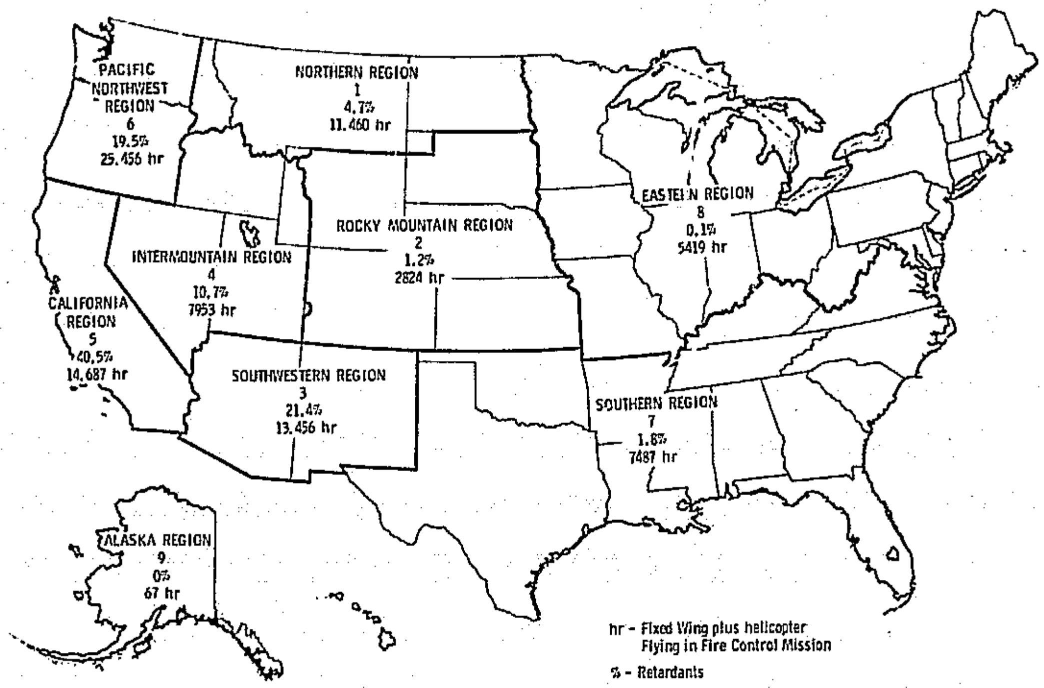


Figure 5-14. USFS Relative Aerial Fire Fighting Activity - 1974

Current operations can be classified as either aerial trankers (fixed-wing) or helicopters. The methods of both deployment and employment differ with these two aircraft types to take advantage of their individual characteristics. The fixed-wing fleet comprises surplus aircraft of relatively large load carrying capacity and includes such designs as the B-17, C-119, DC-6, DC-7, F7F, and PB4Y2 as the principal types. The helicopter fleet consists primarily of the Bell 205, 212, 206, Sikorsky S-61 and others depending on the agency and the area concerned. The helicopters are generally based in the national forests during the fire season in order to respond to a fire in their area within 30 minutes. The fixed-wing aircraft are generally deployed during the fire season from 40 to 100 nm (74 to 185 km) from potential fire areas. Because of the high speed and large capacity of the fixed-wing aircraft compared to the helicopter, they can generally make an initial attack on the fire in approximately the same time and with somewhat greater affect given the same degree of

accuracy in retardant delivery. (However, helicopters, because of their slower speed and greater maneuverability, usually are more accurate.) After the initial attack the fixed-wing aircraft return to their bases for a quick turnaround reloading, refueling as required. The helicopters may return to their bases or, may dip water from a suitable water supply if available nearby, in externally slung buckets. This quick turnaround at shorter range can make a VTOL very effective. Figure 5-15 shows these two missions schematically.

A typical mission distance for a helicopter may be a flight of 25 sm (40 km) from the base to the fire area with several shorter trips of 5-10 sm (8-16 km) to and from a water reservoir. After using up all but its return and reserve fuel, the helicopter will return to its originating base for servicing. If an advanced base is set up (possibly within 5 sm (8 km) of the fire area) for water or retardant supply, fuel will also generally be available, and the helicopter is only required to make the shorter round trips and need not return to its original base of departure until the fire is under control.

The aerial tanker, on the other hand, must generally return to its originating base for both retardants and fuel. The distance is variable, since bases are selected to optimize the coverage of several potential fire areas and must consider the airfield requirements of the aircraft used. Figure 5-16 shows the current deployment in the contiguous 48 states of the United States. Two curves are plotted. The solid line shows the percent of the tanker bases at or less than a given distance from the centroid of the National Forests. For example, 60 percent of the tanker bases now employed are within 80 sm (129 km) of the centroids of all National Forests. The other curve considers the area of the National Forests, and in the example above shows that tanker bases no more distant than 80 to 90 sm (129 to 145 km) cover 70 percent of the National Forest acreage. In high fire potential areas, the distances tend to be less than in low potential areas. Also, when large fires occur, tankers

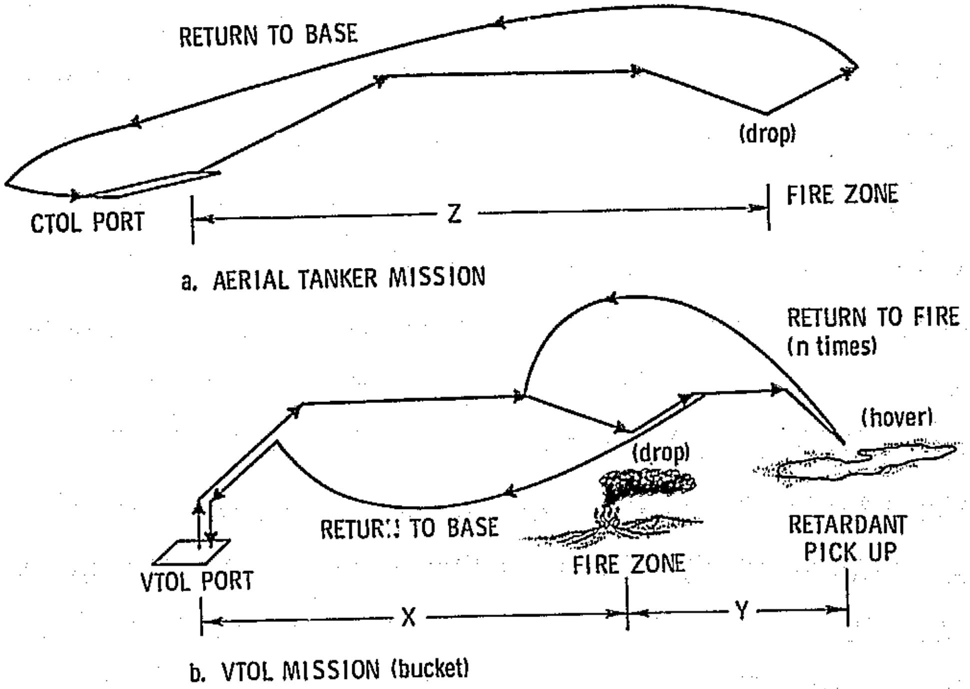


Figure 5-15. Typical Fire Control Missions

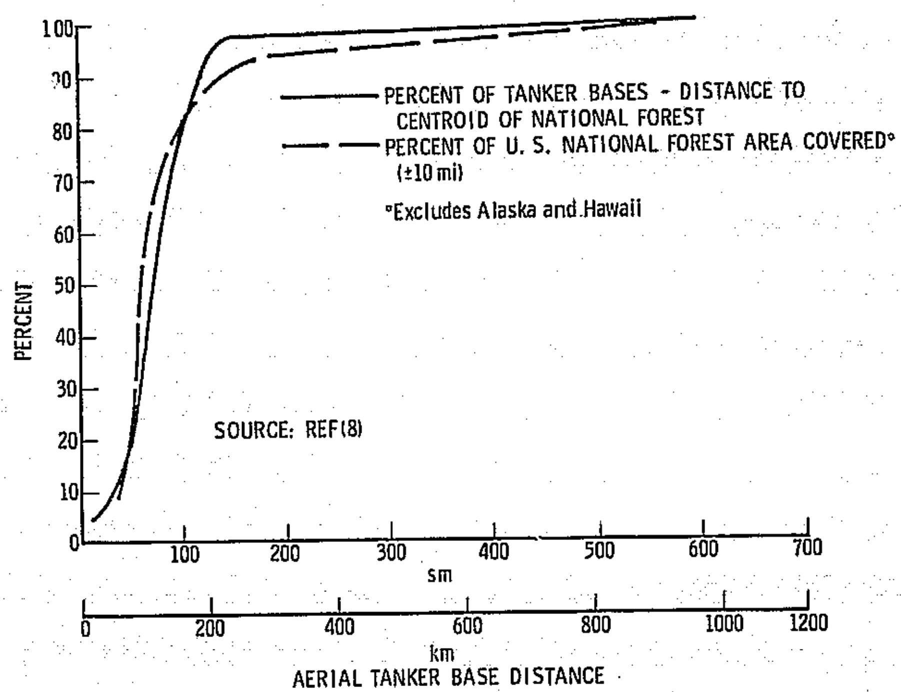


Figure 5-16. Aerial Tanker Range Requirement

may be transferred from their normal bases to the fire area to reinforce the normal tanker complement.

In comparing tanker versus helicopters, not only their speed, load carrying capacity, base distances, and their capability to utilize nearby water supplies must be considered, but also their effectiveness in dropping the retardant, and the type of retardant materials used. Tankers may have relatively sophisticated dump controls employing varying rates of dump and equipped with intervalometers which permit complete shut off if required. (Although use of these devices are possible, not all current tankers employ them.) The helicopter, however, usually employs a bucket on an external sling. This is maneuvered over the fire and opened to salvo the retardant on the fire. The slower speed and highly maneuverable helicopter can place its load with greater accuracy, although it is frequently not in the same volume class as the larger aerial tankers.

Fire is fought with retardants and water. The former is a water-based liquid chemical which, in addition to wetting the area, has a long-term capability to retard a fire. Plain water, on the other hand, tends to dry up quickly - even losing some effectiveness from the time of release to time of impact. There is no simple correlation of the efficiency of water versus chemical retardants, since a number of variables must be considered. However, some studies have used a simple 2 to 1 ratio in favor of retardants. That is, 1 unit of retardants is considered twice as effective as 1 unit of water, or twice the weight of water must be delivered as chemical retardants for the same effect. This study simply uses "retardants" in most all analyses. Where water is compared to chemical retardants, the 2 to 1 ratio is observed and noted. It should also be understood that where natural water is not available, advance bases with portable reservoirs are frequently set up for large fires and water is trucked in. Helicopters can dip from the reservoir. These advance bases are also capable of mixing retardants; thereby permitting VTOL aircraft to dip retardants with their buckets and make a quick turnaround.

2. MISSION PARAMETERS

Because of the differences noted above in the operations of helicopters and fixed-wing aircraft, fire missions can be thought of as two distinct types. One, the aerial tanker mission, and the other the helicopter mission. Because the advanced aircraft concepts considered in this study have large payloads, relatively high speeds, and a VTOL capability, they can operate in both the tanker and helicopter roles. It is left to the analyses to determine just how well each performs. In order to permit this evaluation, two fire control missions were defined.

a. The Aerial Tanker Mission

The Aerial Tanker Fire Control Mission is summarized in Table 5-4. Distance and cargo carried are varied for parametric studies. One important characteristic of this mission not shown, is the low annual utilization rate. The nature of the mission requires that the aircraft stand by in readiness much of the time. Actual flying generally is of the order of 100 hours per year, thus causing the fixed expenses to be shared by relatively few flying hours.

b. The VTOL Fire Control Mission

The VTOL Fire Control Mission is described in Table 5-5. Note that the VTOL mission is at a shorter range (first "en route" segment than the aerial tanker mission. This 25 sm (40 km) distance is typical of the current VTOL missions flown with contemporary helicopters. Distance may be increased for advanced concepts to make use of their greater speed and range capabilities. In this mission the aircraft carries a load of retardants to the fire area, and drops them, then proceeds to a retardant loading area (or water reservoir) assumed to be 5 sm (8 km) away (second "en route" segment), dips a load of retardant (or water), returns to the fire area for a second dump and then proceeds to the departure base. As indicated by the table, the trip to the retardant (or water) loading base and then to the fire may be recycled until fuel expenditure

Table 5-4. Aerial Tanker Fire Control Mission Parameters

Mission Segment	Mission Parameters					Remarks
	Time (Min)	Distance (sm)	Pass (No)	Cargo (lbs)	Altitude (ft)	
Load	5	—	1	a	—	
Warmup	2	—	—	—	—	
Takeoff	1	—	—	—	1500	VTO or STO
En route	—	a	—	—	4500	
Loiter	10	—	—	—	4500	To Permit Spacing
Descent	—	2	—	—	3000	To Drop Altitude
Unload[b]	1.5	—	—	a	3000	Drop
En route	—	a	—	—	4500	Return to Base
Land	1	—	—	—	1500	
Refuel[c]	22	—	—	—	—	Reserve of 45 minutes

[a] Parametrically varied.

[b] The actual definition employs a landing segment between Descent and Unload for computer purposes to establish the altitude to stop descent. However, no time, distance or fuel are associated with this "do nothing" segment and it is omitted from the description above.

[c] Refuel and reloading are accomplished together, this segment sets proper computer conditions and provide some additional time to account for the aircraft's turnaround.

Distances are in statute miles to provide direct comparison with previous studies.

Table 5-5. VTOL Fire Control Mission Parameters

Mission Segment	Mission Parameters					Remarks
	Time (Min)	Distance (sm)	Pass (No)	Cargo (lbs)	Altitude (ft)	
Load	5	—	1	a	—	
Warm Up	2	—	—	—	—	
Takeoff	1	—	—	—	1500	VTO or STO
En Route	—	a	—	—	4500	To fire area
Loiter	3	—	—	—	4500	To permit spacing
Descent	—	2	—	—	3000	To drop altitude
Unload	1.5	—	0	a	3000	Drop
En Route	5	—	—	—	4500	To advance base
Loiter	1	—	—	—	4500	Maneuvering Allowance
Descent	—	2	—	—	2500	To pick up area
Hover	1	—	—	—	2500	Dip retardant load
Load	0.5	—	0	a	—	Load retardant
En Route	5	—	—	—	4500	To fire area
Loiter	3	—	—	—	4500	To permit spacing
Descent	2	—	—	—	3000	To drop altitude
Unload	1.5	—	0	a	3000	Drop
En Route[c]	25	—	—	—	4500	Home or advanced base
Land[d]	1	—	—	—	1500	Land for refueling

b

[a]Parametrically varied.

[b]These segments may be repeated a number of times depending on initial retardant load/fuel load combination.

[c]If advanced base is assumed,distance may be shortened appropriately.

[d]Cycle may be reinitiated - assumes fueling and loading on second cycle are done concurrently. Forty-five minute fuel reserve is assumed.

Distances in statute miles to provide direct comparison with previous studies.

requires a return to base. If the advance base has refueling capability then the final "en route" segment may be of the order of 5 sm (8 km). Thus it may be seen that the nominal mission may be modified by changing the en route distances and the number of times the retardant dipping cycle is repeated. This is controlled by the size of retardant bucket assumed at the initial takeoff point since this determines the maximun fuel loaded. Detailed discussion of the analyses provides additional information concerning the mission parametric variations.

3. MISSION ANALYSES

The Aerial Tanker mission is currently performed by fixed-wing aircraft with large internal tanks flying radius of action distances up to approximately 100 sm (161 km). The VTOL missions, on the other hand, employ contemporary helicopters flying relatively short radius of action missions with externally slung buckets. In the analyses described below, the advanced concepts are assumed to perform similarly to the contemporary aircraft with respect to range and load configuration.

a. Aerial Tanker Mission

The first variant of the fire control mission considered is the Aerial Tanker Mission shown in Figure 5-15a. This mission is analyzed by parametrically varying the distance (z) and the load of retardants carried to the fire. As z was increased, the retardant load (payload) was decreased to maintain the aircraft at its maximum gross weight for takeoff. Fuel loaded was sufficient for the round trip plus a 45-minute reserve at 10,000 feet, (3000 m) flying at the maximum range speed at the weight after retardant drop.

Figure 5-17 shows the rate of retardant delivery capability for the three advanced concepts. The Lift Fan aircraft is operated in the STOL mode permitting its takeoff gross weight to reach 45,000 lb (20,412 kg) (instead of the 34,426 lb (15,615) kg) for VTOL operation. The STOL mode, coupled with the lift fan aircraft's greater speed capability enables

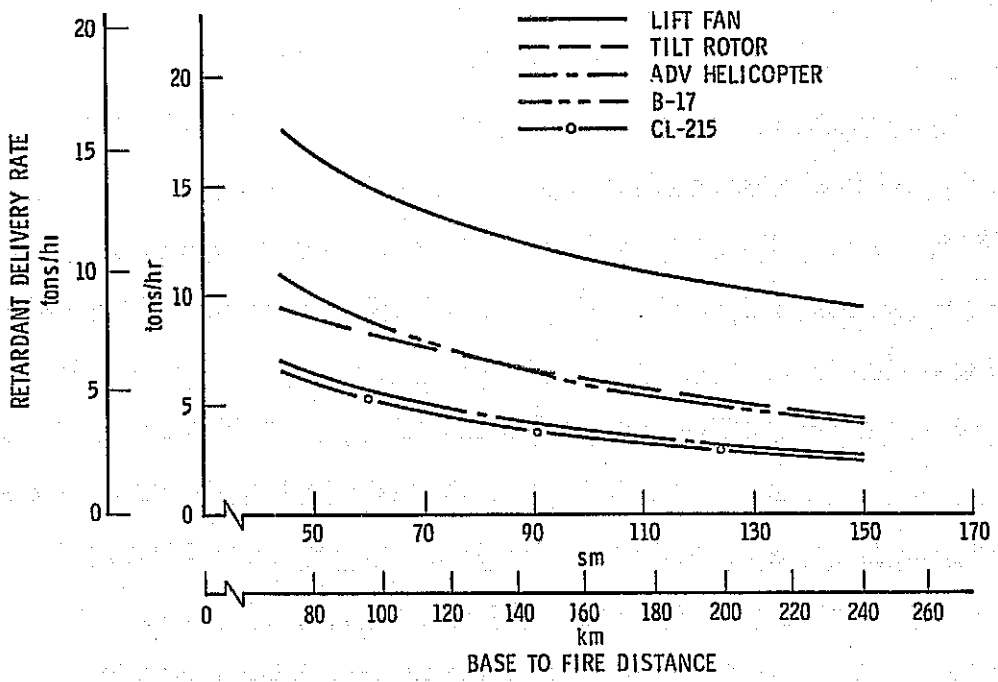
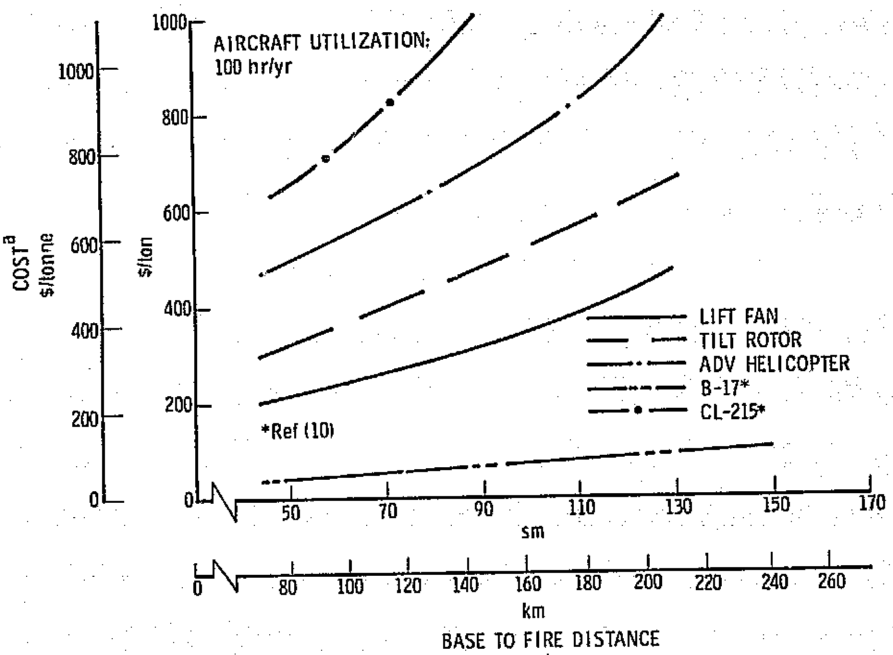


Figure 5-17. Rate of Retardant Delivery - Aerial Tanker Mission



[a] Not Including Cost of Retardants

Figure 5-18. Cost of Delivering Retardants to Fire-Aerial Tanker Mission

it to achieve a rate of delivery approximately 60 percent greater than the tilt rotor and 140 percent greater than the advanced helicopter. Data for two contemporary aircraft flying as aerial tankers are also shown for comparison (Reference 10). The B-17 delivery performance is generally equal to the tilt rotor, but exceeds the advanced helicopter performance. The B-17, which can carry up to 20,000 lbs (9072 kg) of retardants, is typical of the larger aircraft currently employed. It is used in this analysis for both performance and cost comparison. Because of its vintage and war surplus origin, its costs tend to be quite low. The Canadair CL-215, on the other hand, is a commercial design made specifically for "water bombing" and is representative of the performance and costs of contemporary production aircraft used in this mission. From Figure 5-17 it can be seen that all three advanced V/STOL aircraft are performance competitive with the contemporary aircraft.

The information presented in Figure 5-18 relates the cost of delivery to the range (radius of action) of the operation, and compares the three advanced concepts with the two reference contemporary aircraft. Here, the B-17 with its low cost and large load shows its outstanding all-around performance. The other four aircraft demonstrate the impact of high fixed costs when spread over a utilization of only 100 hours a year. On a cost performance basis, the lift fan aircraft is the closest competitor to the B-17 and all three advanced concepts are better than the Canadair CL-215.

It must, in all fairness to the CL-215, be explained that the Canadair aircraft was not designed to operate in the mode defined by the mission described here. The CL-215 design mission is best described by its flying to a fire area, dropping its retardant load, and then skimming a nearby body of water to pick up another water load, returning to the fire, and then repeating this cycle until low fuel or fire control dictate its return to base. In this way, its delivery rate is greatly enhanced and its higher operating costs justified. For effective employment, however,

it must be used where relatively large bodies of water exist (Reference 10). However, the use of CL-215 data does establish some reasonable bounds on new technology operational and cost performance, and is included here for these reasons.

All new technology aircraft suffer in the fire control missions because of the relatively low utilization rates. It may be understandable to keep a 30-year old B-17 idle most of the time, but utilization of a multi-million dollar aircraft at 100 hours per year is expensive and difficult to justify. The new aircraft may be kept busy, either using their increased productivity to reduce the total fleet size, or by alternative uses in compatible missions. In this way, the annual fixed costs (depreciation, insurance, etc.) will be amortized over a greater number of hours and the equivalent hourly rates will be commensurately reduced. Figure 5-19 shows the effect of increased utilization on hourly costs. In order to get significant reduction in operating costs it appears that 400 hours (or more) per year

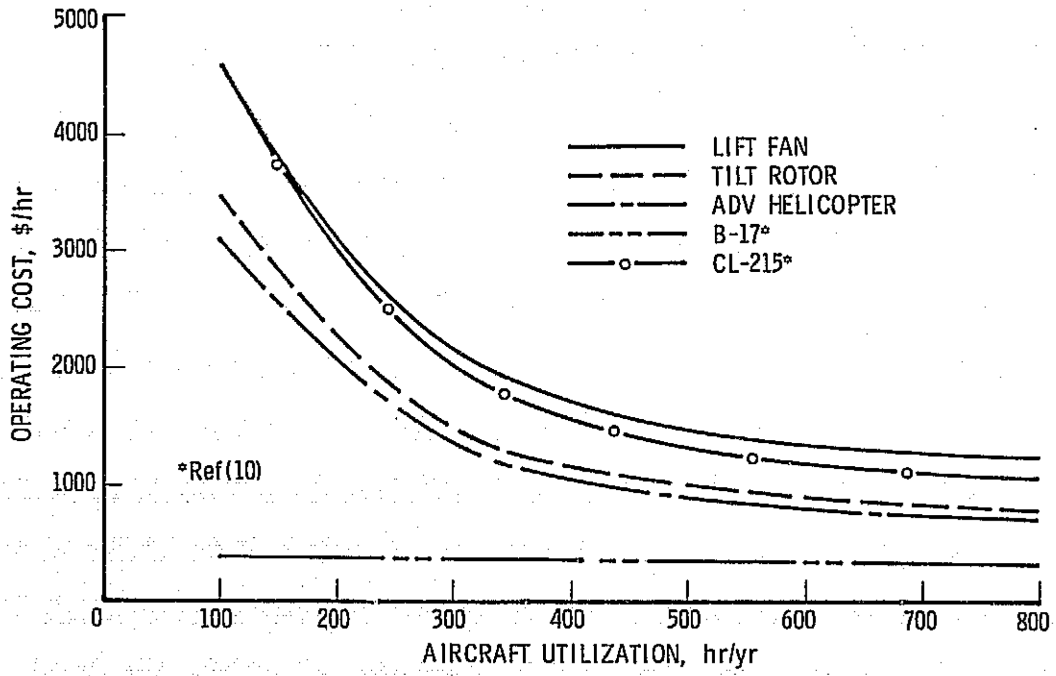


Figure 5-19. Hourly Operating Costs - Aerial Tanker Mission

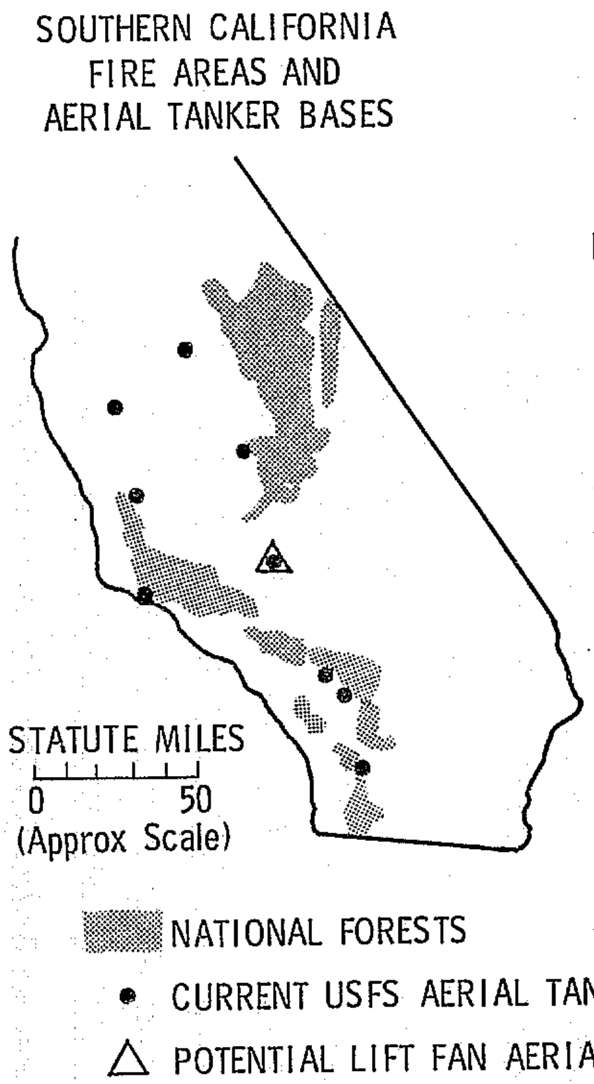
should be the goal. It is significant that the B-17 costs are not notably affected by utilization.

One other point should be borne in mind. The costs used for contemporary aircraft (B-17 and CL-215) represent the costs to the government of contract use. Therefore, an operator's profit is built into these data. However, the costs associated with the advanced concepts are those expected at the operator level. If the operator is a contractor, the ultimate user must expect to pay more in order to provide a return on investment (ROI) to the operator.

From the foregoing it is apparent that the lift fan aircraft (in the STOL mode) is the most cost effective of the three advanced concepts. For this reason, the lift fan aircraft is further analyzed in a typical fire control deployment situation to see what costs are expected. Figure 5-20 shows the locations of USFS contract Aerial Tanker bases in Southern California, and the potential fire areas the tankers protect. The following analysis is summarized on the figure.

The analysis assumed that one B-17 was deployed at each of the nine bases, and that two aircraft respond to every fire. Further, it was assumed that the mean range to the fire areas throughout the year will be 40 sm (64 km) and the B-17's are flown an average of 100 hours per year, each. Figure 5-17 indicates that at 40 sm (64 km) a B-17 can deliver approximately 11 tons (9979 kg) of retardant per hour. Therefore, in a year a total of 9900 tons (8,981,129 kg) will be delivered by the nine B-17's at a total cost of $360,000.

Again, reference to Figure 5-17 indicates that for a delivery rate of 11 tons (10 tonnes/hr) per hour, the lift fan aircraft may be deployed at a range of 80 sm (129 km). The base represented by the triangle on Figure 5-20 is approximately situated such that the mean distance to fires during the year is about 80 sm (129 km). Thus, we see that potentially one lift fan aircraft base could be selected to give the same coverage as nine B-17 bases. To deliver the required weight of retardants (9900 tons)



ANALYSIS SUMMARY

Assumptions:

One B-17 per current base
A minimum of two B-17's respond to a fire
B-17 mean distance to fires - 40 st mi
Lift Fan Mean distance to fires = 80 st mi
B-17 utilization 100 hrs/yr/aircraft

B-17 Productivity and Costs:

B-17 delivers 10 tons/hr at 40 miles (Figure 5-17)
9 aircraft x 11 tons/hr x 100 hrs/yrs = 9900 tons/yr
B-17 costs $400/hr at 100 hrs/yr (Figure 5-17)
900 hrs/yr x $400/hr = $360,000 per year

Lift Fan Productivity and Costs:

Lift Fan delivers 11 tons/hr at 80 miles (Figure 5-17)

$$\text{Annual flying hours} = \frac{9900 \text{ tons/yr}}{11 \text{ tons/hr}} = 900$$

A minimum of two Lift Fans would be required to meet retardant delivery rate of 2 B-17's

Cost = $1600/hr (utilization = 450 hrs/yr)

900 hrs/yr x $1600/hr = $1,440,000/yr

Figure 5-20. Lift Fan Aircraft Aerial Tanker Analysis

(8981 tonnes) in a year the lift fan aircraft must fly 900 hours (the same total as the B-17's). If only one lift fan aircraft were used, this utilization rate would result in a cost of approximately $1200 per hour for a total annual cost of $1.08 million. However, one lift fan aircraft could not deliver at the same rate as the two B-17 aircraft assumed; also, it would not seem prudent to assume only one fire at a time; or, that the one aircraft would alsways be available when needed. Therefore, two lift fan aircraft were assumed to fly 450 hours per year, each, at a cost of $1600 per hour for a total annual cost of $1.4 million.

The cost of using the lift fan aircraft would exceed the cost of the B-17's by at least $1 million per year. The cost would be even more if operated on contract with a suitable ROI added. Although some savings could result by having eight fewer bases (the savings due to fewer bases is an unknown factor, since the airports are for general use and would be there anyway. The only savings expected would be those associated with fewer contractor facilities.)

The analysis of the Aerial Tanker Mission concludes that the operational performance of the advanced concepts is generally equivalent to large surplus tankers currently in use; and that the lift fan aircraft in the STOL mode is generally superior in operational performance to contemporary aerial tankers. However, the economics of the advanced concepts are such that it is unlikely that they will be employed in any significant numbers so long as there are surplus war and commercial aircraft types that can be adapted to the mission. The low utilization and attrition rates of the current aerial tanker fleet, coupled with the large number of surplus reciprocating, 4-engined, commercial airliners makes utilization of the advanced V/STOL's as dedicated aerial tankers unlikely.

b. VTOL Fire Control Mission

The second variation of the fire control mission is the VTOL mission wherein a bucket carried as an external load is used to transport retardants

to the fire area. This mission differs in several ways from the tanker mission previously examined. First, since the load is external, the aircraft's speed may be constrained in order to permit the load to assume a safe and stable position in tow. Current use of external load buckets permits speeds up to normal cruise speed of contemporary helicopters, and it was assumed, for this study, that proper bucket design permits speeds up to approximately 250 kts.[1] Second, the external load increases fuel consumption rates, reducing the range of operations for a given load. The effort allocated to this mission did not permit a detailed examination of these drag effects and a simple 10-percent penalty was assumed. The third effect of this mission configuration is the imposition of a constant cargo weight fixed by the size of the bucket. The assumed bucket size fixes the fuel load available at the initial takeoff, and establishes the number of retardant cycles without subsequent refueling. Also, with a fixed cargo size, the effective load factor steadily decreases with each cycle, yielding a lower overall load factor for the mission. This effect is treated in more detail later in this section.

The rate of retardant delivery is shown in Figure 5-21 as a function of the distance from the fire to the retardant supply base. In this case, the main VTOL base has been assumed to be 25 sm (40 km) distant from the fire. The retardant supply base maximum range is limited by the main base to fire distance since the aircraft will fly to either the main base or the fire retardant supply base, whichever is closer.

For reference purposes, the delivery rates of two contemporary fire fighting aircraft are shown, the Sikorsky S-61 and the Canadair CL-215. Although not a bucket carrier, the CL-215 operates in a comparable mode by scooping water from large bodies of water.[2]

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[1] It will be seen later that the practicality of this hypothesis has little bearing on the conclusions drawn from the analysis.

[2] The upper delivery rate curve for the CL-215 assumes all aircraft are delivering water. If all the other aircraft are delivering chemical retardants, the CL-215 is only one-half as effective, and the alternate delivery rate curve for the CL-215 must be used for proper comparisons.

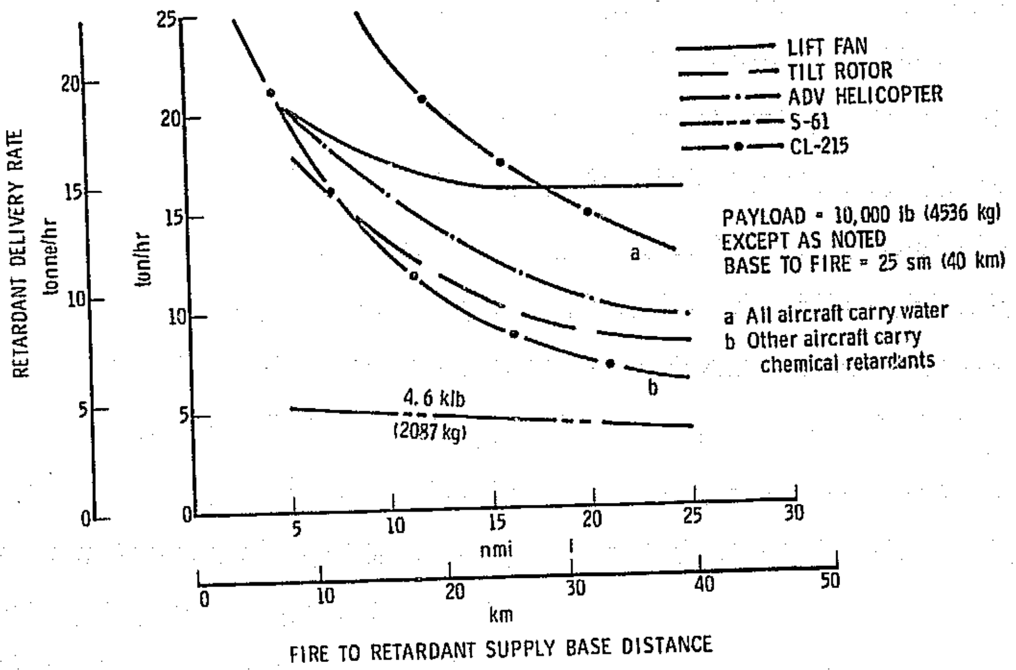

Figure 5-21. Delivery Rate as a Function of Range

Because of its higher fuel consumption, the lift fan aircraft soon reaches the point where cycling to the retardant supply base is of little benefit. At the 5 sm (8 km) range, the fuel supply is adequate for three cycles. Counting the initial drop, the lift fan aircraft is able to deliver four 10,000 lb (4536 kg) loads on one fuel load. At the 15 sm and 25 sm (24 km and 40 km) ranges, the lift fan is only capable of making two cycles to the retardant supply base, and the small difference in delivery rates for the 15 sm and 25 sm (24 km and 40 km) ranges results from the small incremental time to fly the 15 sm and 25 sm (24 km and 40 km) missions.

On the other hand, the range does affect the delivery rates of the other two concepts significantly. For example, the advanced helicopter is capable of 17, 12, and 8 cycles at 5 sm, 15 sm, and 25 sm (8 km, 24 km, and 40 km) ranges, respectively, to the retardant base.

It is interesting to compare the ability of these aircraft in the tanker and bucket missions. With reference to Figure 5-17, it may be seen that

at 25 sm (40 km) the lift fan delivers approximately 18 tons (16,329 kg) per hour as a tanker. From Figure 5-21, it may be concluded that only at the 5 sm (8 km) range to the retardant base is it worthwhile to operate the lift fan in the bucket mode. At 10 sm (16 km), the bucket delivery falls below that of the tanker.

The tilt rotor, on the other hand, has a higher delivery rate in the bucket mode for retardant base distances below 15 sm (24 km). Beyond that distance, it would be better to operate it as a tanker.

The advanced helicopter, as might be expected, is more efficient, however, as a bucket carrier than a tanker for all ranges of the retardant base shown.

All the above comparisons have been made on the basis of delivery rates. The costs of retardant delivery have not been considered as yet. Figure 5-22 shows the comparative costs of the various aircraft in the bucket mode of operation. That the costs appear reasonable compared

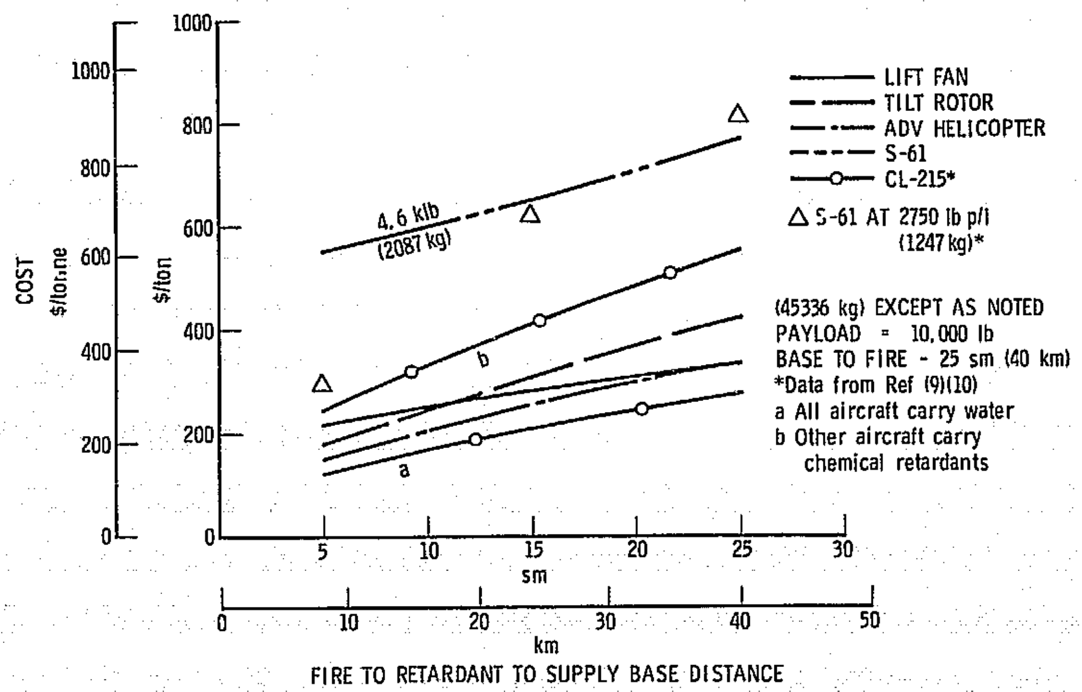

Figure 5-22. Cost of Delivery as a Function of Range

to the two contemporary aircraft shown is significant. Another source of S-61 cost data is shown for comparison. The disparity noted between the two data points is the result of some mission parameter variations as well as differences in estimated operating costs in the two methods.

Comparison of the costs of Figure 5-22 with those of Figure 5-18 shows, without question, that for short-range missions (i.e., 25 sm (40 km) to the fire area) the tilt rotor and advanced helicopter should be used in the bucket mode rather than as tankers. The use of the lift fan is not so clear-cut, costing \$200/ton (\$181/tonne) as a tanker and \$220/ton (\$200/tonne) with a bucket.

It is interesting to note that the CL-215 is obviously not operated optimally when used as a conventional tanker. Its cost of delivery is approximately \$100/ton to \$300/ton (\$91/tonne to \$272/tonne) scooping, as compared to \$600/ton (\$544/tonne) as a tanker, at the same range to the fire.[1]

Other mission payloads were examined in the range of 4,000 lb (1814 kg) and 6,000 lb (2722 kg). It was found that, for variations in range to the retardant supply base, the higher loads optimize the flights. However, for a fixed distance from the fire to the retardant base, the initial payload plays a significant role in the delivery rate and, to a lesser degree, in the cost of operation. This results from the situation mentioned previously; namely that, in using a bucket of fixed dimensions, the payload per cycle is fixed, as well as the initial fuel load. As fuel is burned, the aircraft is capable of picking up additional payload; but since the bucket size is fixed, it may not do so. It is impractical to assume

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1 Considering that as a tanker the aircraft may deliver chemical retardants which are twice as effective as the water delivered by the "scooper," the tanker version is about as cost effective as the scooper. The alternate CL-215 curve shows this situation.

a bucket sized for the final cycle payload and only partially filled, initially. (Since no practical control in filling is available on dipping, the bucket could be completely filled on the first cycle, thereby overloading the hovering aircraft.) Thus, as the mission progresses, the average load factor for each retardant drop decreases from its maximum value of 50 percent. (A 50-percent load factor is the maximum per cycle since the aircraft is flying fully loaded on the trip to the fire and empty on the trip back.)

From the situation described above, it is obvious that some initial load is optimum. Figure 5-23 indicates how the delivery rates for the various aircraft vary as the initial payload is changed. The data of this figure represents the case where the distance to the retardant base is only 5 sm (8 km). For the longer ranges to the supply base, the curves are similar, except that they are shifted downward. Initial payload weights of 10,000-11,000 lb (4536-4990 kg) appear to be optimum for the tilt rotor and lift fan, while the advanced helicopter tends to optimize at a higher initial weight. This results from its slightly greater load carrying capacity and better fuel consumption. The S-61 data computed by using the mission analysis program are plotted for comparison. One additional S-61 data point from the referenced study is also shown. The data obtained from the reference for the CL-215 is shown by footnote.

Figure 5-24 shows how delivery costs vary as a function of initial payload weight. Since aircraft operating costs vary as a function of operating time, the more efficient delivery rates result in the least costs per ton.

Since it is obvious that the tanker mode is generally more beneficial to the lift fan than the bucket mode, an attempt was made to show how the lift fan may be utilized optimally. It was assumed that the lift fan operates as a tanker (i.e., all retardants are carried internally, thereby reducing drag and permitting higher speeds, but follow the mission profile of the bucket mission). To do this, it is necessary to assume either that the aircraft is equipped with high-volume pumps that can take in water from hoses

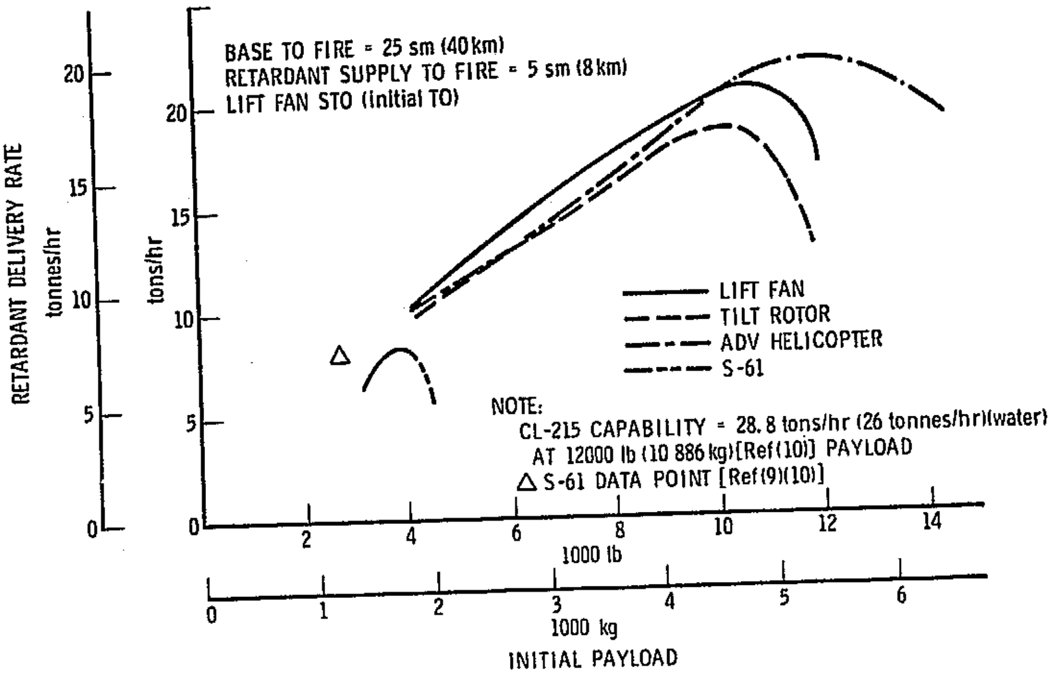

Figure 5-23. Delivery Rate as a Function of Initial Payload

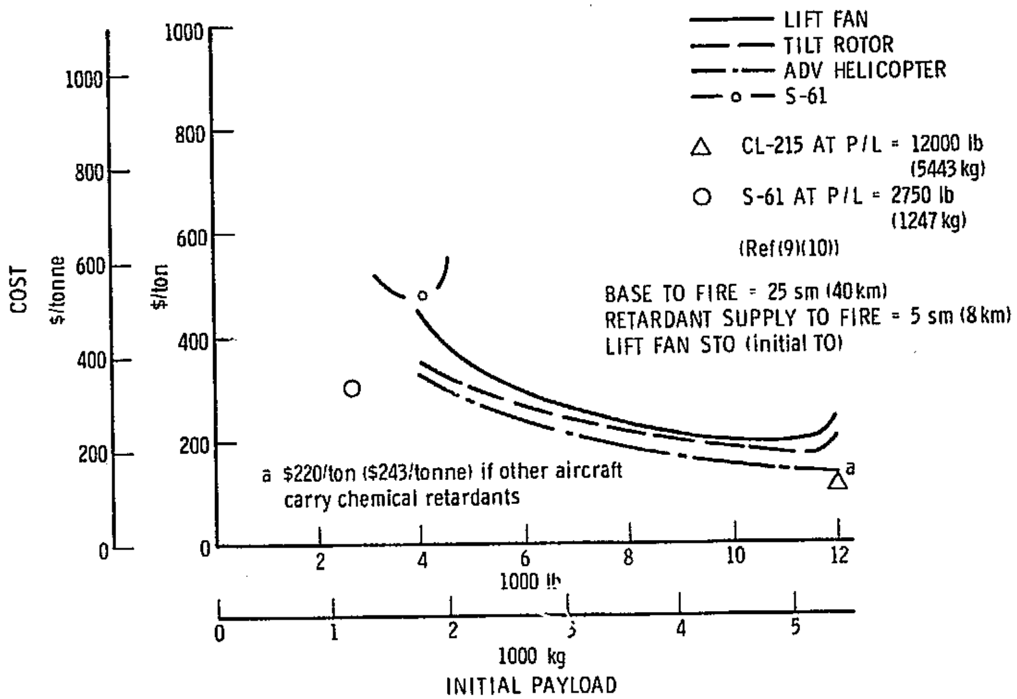

Figure 5-24. Cost of Delivery as a Function of Initial Payload

extending into a reservoir from hover, and that proper weight control can be maintained during the retardant tank recharging; or, that the aircraft is being landed at the retardant base (VTOL) and ground-based pumps provide the loading. In this way, an increase in payload is allowed at each loading to make up for fuel consumed.

Figure 5-25 shows the results of this analysis. The dashed curve represents the data for the fully loaded lift fan VTOL tanker while the solid line is the lift fan data in the bucket mode from Figure 5-23, shown for comparison. The combined effects of using internal tanks, thereby reducing drag and allowing an increase in speed plus the maximizing of each cycle's load, are shown. It appears that an initial load of 9,000 lb (4082 kg) provides the greatest rate of delivery. Figure 5-26 is a companion set of curves showing the cost comparison of the two modes of operation. The cost curve for the VTOL tanker version is quite flat in its optimum range, showing little sensitivity to loading.

Applying the VTOL tanker concept for all three advanced aircraft yields the interesting results shown in Figures 5-27 and 5-28. In the first of these figures, it may be seen that both the tilt rotor and advanced helicopter exceed the lift fan's performance in delivery rate. The second figure shows that the advanced helicopter and tilt rotor have comparable delivery costs which are significantly below those of the lift fan and are competitive with the CL-215 (if all are carrying water).

As indicated previously in Figure 5-19, the utilization rate of only 100 hours per year severely penalizes any new aircraft when compared to older aircraft. However, in the VTOL missions under analysis, few "old" aircraft are available to perform the mission, and the new concept may operate on parity with most of the contemporary aircraft employed. However, because of their increased operational capacity, the new VTOL concepts are more adaptable to other missions. For this reason, it is more probable that the same aircraft can be employed in two or more compatible missions during the course of a year, thereby raising its

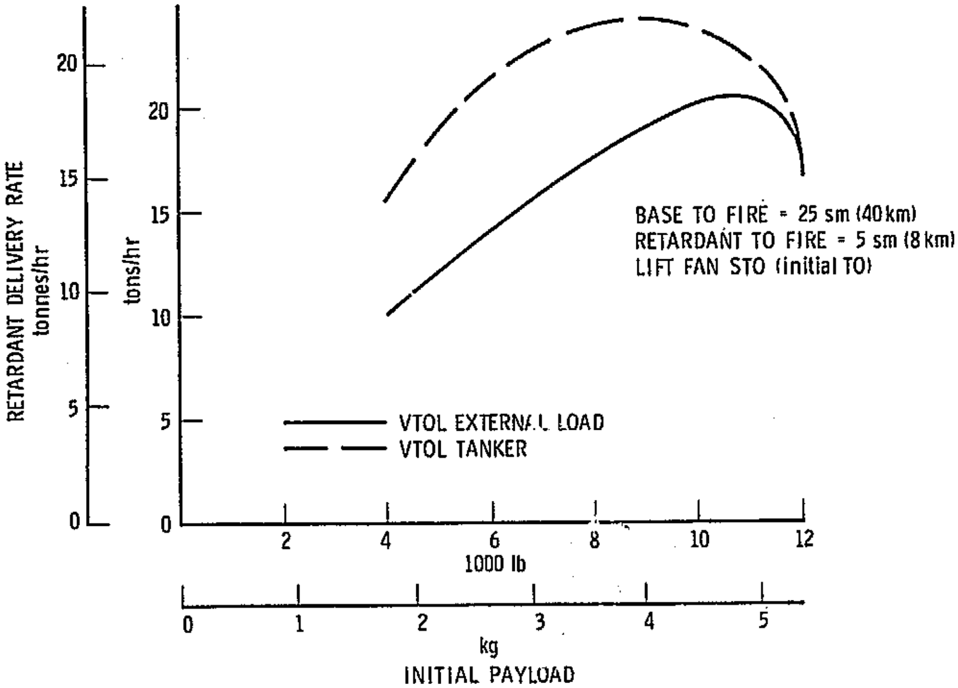

Figure 5-25. Lift Fan Aircraft Retardant Delivery Rate

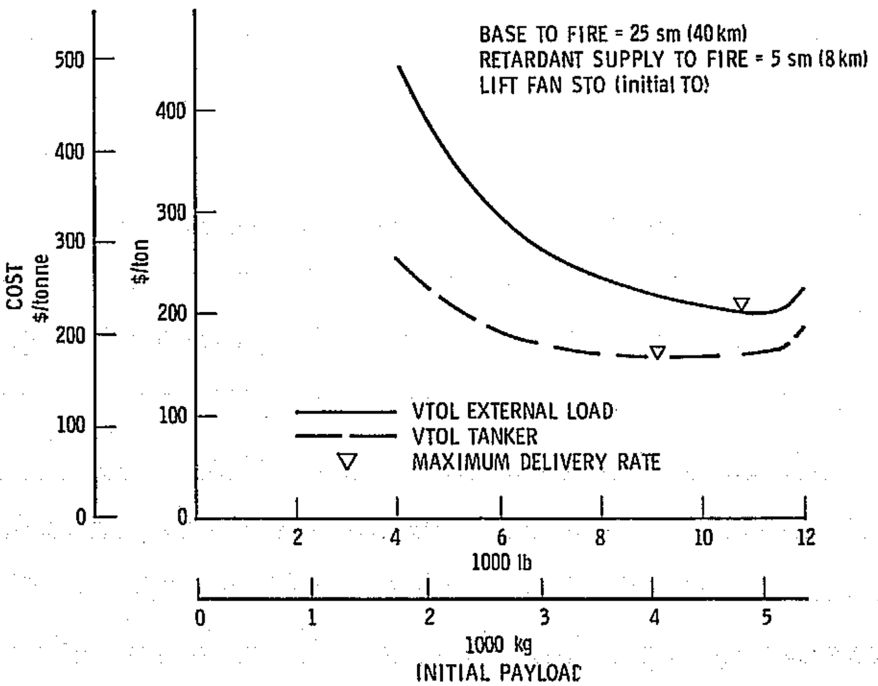

Figure 5-26. Lift Fan Aircraft Retardant Delivery Cost

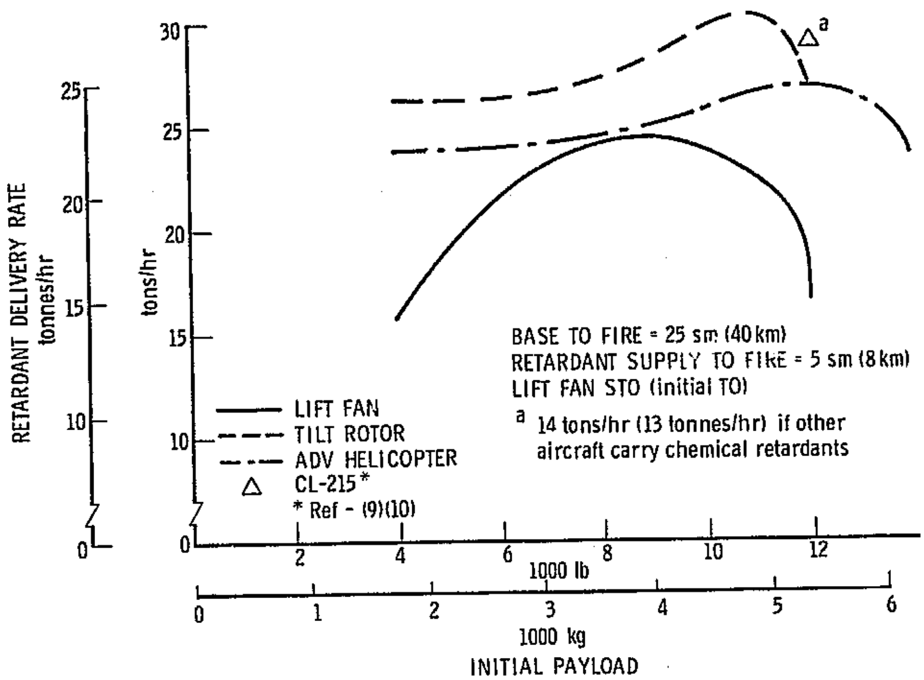

Figure 5-27. Retardant Delivery Rate as a Function of Initial Load

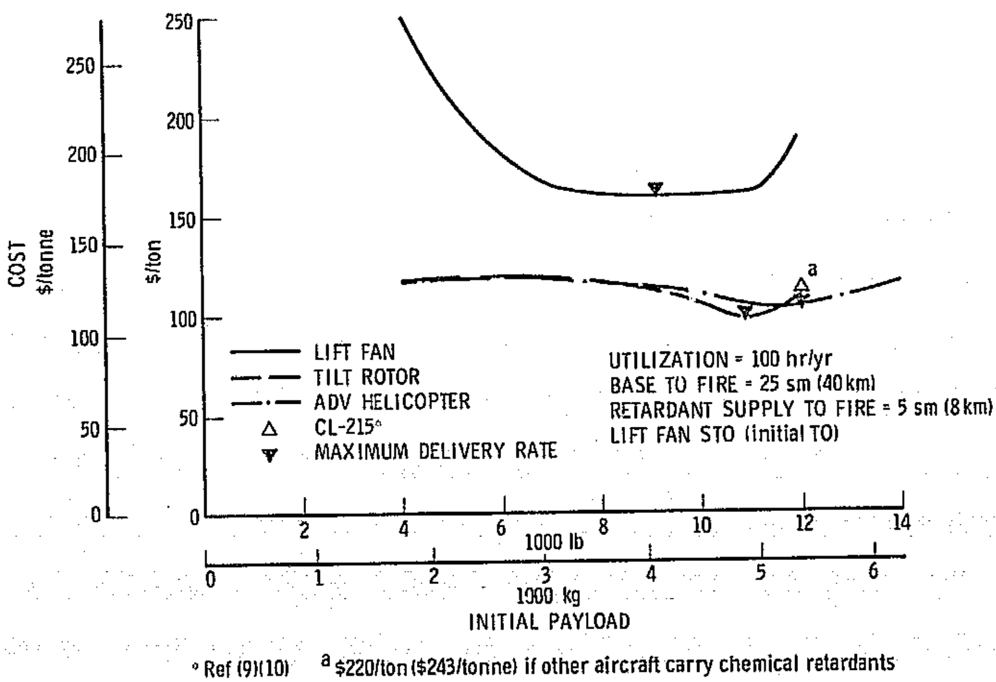

Figure 5-28. Retardant Delivery Cost as a Function of Initial Load

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annual utilization rate. Increasing utilization up to 400 hours per year will result in an hourly cost reduction of approximately 66 percent. Under optimum employment conditions[1], this could result in the delivery costs for the tilt rotor and advanced helicopter dropping to the range of \$50/ton (\$45/tonne) and the lift fan dropping to approximately \$75/ton (\$68/tonne). This places these aircraft in a cost-competitive position with the older tankers (reference Figure 5-18) and in a superior position regarding delivery rates. From Figure 5-17, it may be seen that a B-17 at 40 sm (80 km) delivers at a rate of 10 tons per hour (9 tonnes per hour). Once the VTOL tanker reaches the fire area, it can deliver over twice that rate. A tradeoff of initial attack time for the much higher delivery rate suggests that some optimum deployment (location of bases to give wide area coverage) of these advanced aircraft can be made both to reduce the required number and to permit their utilization in a compatible fashion for other missions. Both of these steps tend to increase aircraft utilization with attendant cost reductions.

This analysis concludes:

(1) The strictly aerial tanker mission is not a reasonable mission for the new concepts because of their higher operating costs;

(2) The employment as externally loaded VTOL's is improper because of the possible speed restrictions and higher fuel consumption;

(3) The employment as "VTOL tankers" is a highly viable mission.

The characteristics of high load capacity, high speed, a VTOL capability to permit servicing with retardants at a forward base, and the ability to maneuver over a fire, give these aircraft great promise as "VTOL tankers."

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[1] That is, when used as VTOL tankers from advanced fire retardant supply bases; stationed in areas where they could be used for other purposes, with priority for fire alert during the fire season; used with quick change skid tanks to convert to VTOL tankers.

Table 5-6. Summary of Fire Control Aircraft Characteristics

Aircraft	Takeoff Weight lb (kg)	Max[a] Payload lb (kg)	Speed[b] kt (m/sec)	Speed[b] (ext. load) kt (m/sec)	Cost[c] $/Flight Hr
Lift Fan (VTO)	34426 (15615)	12000 (5443)	470 (242)	245 (126)	4500
Lift Fan (STO)	45000 (20411)	20000 (9072)	470 (242)	245 (126)	4500
Tilt Rotor	33000 (14969)	12000 (5443)	280 (144)	225 (116)	3450
Advanced Helicopter	31500 (14288)	14000 (6350)	180 (93)	180 (93)	3100
Canadair[d] C6-215	43500 (19731)	12000 (5443)	148 (76)	N/A	4600
Sikorsky S-61	19000 (8618)	6000 (2722)	117[d] (60)	110 (57)	3459[d] 2900[e]
Boeing[d] B-17	53000 (24040)	20000 (9072)	152 (78)	N/A	402

[a] Approximate with minimum fuel

[b] Average cruise assumed

[c] Average @ 100 hours/year

[d] Reference (10)

e Value from this study

It is noted that, to the extent that the economic model truly represents the probable costs of the three advanced aircraft, the tilt rotor and advanced helicopter are preferred for this mission over the lift fan aircraft. Considering only the delivery rate, the tilt rotor excels the other two concepts with the advanced helicopter being slightly better than the lift fan aircraft. However, considering its speed advantage, the lift fan would be able to protect a greater area from remote bases than would the advanced helicopter.

Table 5-6 summarizes the aircraft characteristics derived or used in the analysis of the fire missions. Some of the parameters varied slightly with the different situations examined; however, the averages shown approximate the values pertaining to these missions.

Earlier in the discussion of the fire mission, it was mentioned that water and "fire retardants" differ in their abilities to control fires. Throughout this discussion, the term "retardants" is generally used to cover both water and chemical retardants. In the tanker mission discussed first, this does not present a problem since all aircraft return to the main base and can be filled with chemical retardants. The dipping missions by using buckets, however, may be a different matter. The VTOL aircraft can dip water from reservoirs, or water or retardants from tanks at the retardant bases. The CL-215, however, is constrained to the use of water only, when away from its main base, since it scoops its load from a body of water. For the dipping missions, if it is assumed that the VTOL's carry chemical retardants, the effectivity of the CL-215 is halved (application of the rule of thumb), and the cost of delivering a comparable fire control load is doubled. Thus, the VTOL aircraft performance compared to the CL-215 differs, depending on whether water or chemical retardants are used. For this reason, some of the figures show two curves for the CL-215.

E. THE TRANSPORT MISSION

The mission is concerned with the transportation of people and cargo by other than scheduled airline operations. Typically, it is represented by the air taxi mission or the corporate executive mission.

Since the latter is possibly the principal beneficiary of the advanced aircraft design, this analysis models the executive mission.

1. CURRENT OPERATIONS

The executive mission is very broad in its application and varied in its description. It is generally defined as the transportation of the business executive by air, employing a professional pilot or a crew. Thus, the self-flying businessman is excluded from this mission. Because a crew of two is usually employed, larger, usually twin-engined, aircraft are used. Aircraft size varies typically from small twin-engined machines to turboprops, or to turbo jets. Trips typically range from 100 miles (185 km) to over 1000 miles (1852 km) and may be regional or international in nature. Executives all over the world enjoy this use of aircraft and have found it to be effective in conducting their business affairs. Currently, the products of the U. S. aircraft industry predominate in this market.

A previous study conducted by The Aerospace Corporation (reference 11) defined in some detail the varying requirements for this mission. Figure 5-29 pictorally represents the mission and shows it as performed by a VTOL and CTOL. A STOL mission could conceivably operate from some corporation parking lots, but more practically would use a nearby small general aviation airport. Since only one of the advanced concepts (the lift fan aircraft) was assumed to operate in the STOL mode, this analysis considers primarily the VTOL and CTOL modes, with appropriate notations of the lift fan aircraft in the STOL mode.

2. MISSION PARAMETERS

Table 5-7 presents the executive mission in terms of its standard segments. It should be noted that the mission does not include the ground access and distribution times shown in Figure 5-29. Only the flying segments are accounted for in the table. Later, where the ground times play a significant role, proper allowances are made for them.

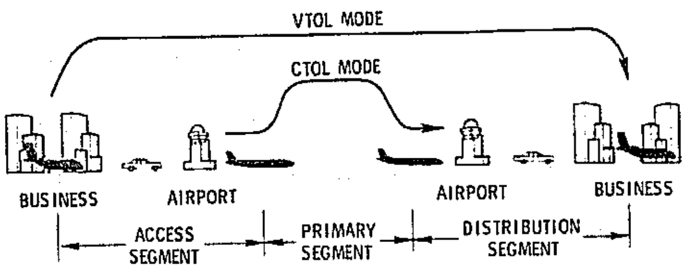

Figure 5-29. Executive Transport Mission Profile

Table 5-7. Executive Transportation Mission Parameters

Mission Segment	Time (min)	Distance (nm)	Passenger (No.)	Cargo (lb)	Altitude (ft)	
Load	10	-	12	240	-	Passenger weight: 180 lb
Warmup	5	-	-	-	-	
Taxi	5	-	-	-	-	CTOL only. STOL: 3 min.
Takeoff	1	-	-	-	0	
En Route	-	a	-	-	5000	Minimum altitude
Land	1	-	-	-	0	
Taxi	5	-	-	-	-	CTOL only. STOL: 3 min.
Unload	10	-	12	240	-	
Standby	180	-	-	-	-	

[a] Parametrically varied.

The interior of the executive aircraft is usually arranged for low-density seating, with tables to permit in-flight work, and lounges sometimes provided. For this reason, the normal seating capacity of the three aircraft under study was reduced from 23 to 12 passengers in the executive configuration. Some weight penalty can be expected as a result of the change in interior design; therefore, the same empty weight was retained even though 11 passenger seats were assumed removed.

The Falcon 30 aircraft manufactured by Dassault of France is used for a standard of comparison. This aircraft was selected since it is comparable in weight to the aircraft under analysis, although in size it is somewhat larger. The Falcon 30 normally seats from 30 to 40 passengers, but it was assumed to be configured to accommodate 20 passengers for the executive mission. Thus, all concepts were assumed to be operating, generally, at approximately 50 percent of their design nominal passenger loads.

3. MISSION ANALYSIS

The previous Aerospace study (reference 11) showed that the nominal medium to long-distance executive mission varies from 300 nm to 500 nm (556 km to 926 km) in distance and carries from 5 to 15 passengers. Thus, it can be expected that, even in the executive configuration, the aircraft rarely will be completely full. This fact makes comparisons of costs per seat mile, or per passenger mile, meaningless. Therefore, this analysis uses, as a standard of measure, the cost-per-trip unit distance as a function of distance which is insensitive to seating configuration or load factor. Since the cost-per-trip unit distance is not sensitive to the load factor, it provides a consistent measure of the cost of flying the aircraft on any given trip distance, regardless of the number of passengers or the seating configuration. Passengers less than, or in excess of, the nominal load used in this analysis could be carried at the same trip cost. Only the maximum ranges shown would be changed because of the tradeoff between passengers and fuel. Costs per passenger mile may be found by dividing

the trip distance costs by the number of passengers assumed for the trip. The cost-per-trip distance is believed to be a more significant comparative performance parameter for this mission than cost-per-seat mile since, in most instances, a number of seats in the typical aircraft flying the executive mission will not be occupied.

In Figure 5-30, the cost-per-trip unit distance is shown for the three advanced concepts and the Falcon 30 as a function of trip distance. The maximum ranges for all four aircraft for this mission are also shown. Since the lift fan can operate in both a VTOL and STOL mode, ranges for both modes of operation are shown. (The lift fan operating as a STOL has a maximum range of 1900 nm (3519 km)). The cost of the VTOL or STOL lift fan aircraft is essentially the same for both modes below 1100 miles (2037 km). (In actual practice, some savings could result from selecting the STOL option because of slightly less fuel used for takeoff and landing and reduced maintenance; however, the modeling used in this study was not sensitive to these slight variations.) However, as will be seen later, some time penalties are associated with the use of the lift fan STOL not applicable to the VTOL.

The lift fan aircraft curve follows the general shape of the Falcon 30 curve, and both aircraft have marked decreases in operating costs for the long-range missions. This results from the higher cruise altitudes practical at long ranges, giving better speed and reduced fuel consumption. On the other hand, the tilt rotor curve exhibits characteristics of the advanced helicopter curve, showing only moderate cost savings with range. This results from the tilt rotor's characteristic of reduced cruise speed with increased cruising altitude. Even though the fuel consumption rate continues to decrease with altitude, and the longer cruise time resulting from the slower airspeeds yields only moderate fuel savings, the increased costs of other operating expenses more than cancel any fuel savings. In all four cases, the longer flights tend to be less expensive since the relatively high costs associated with takeoff, climb, and landing are

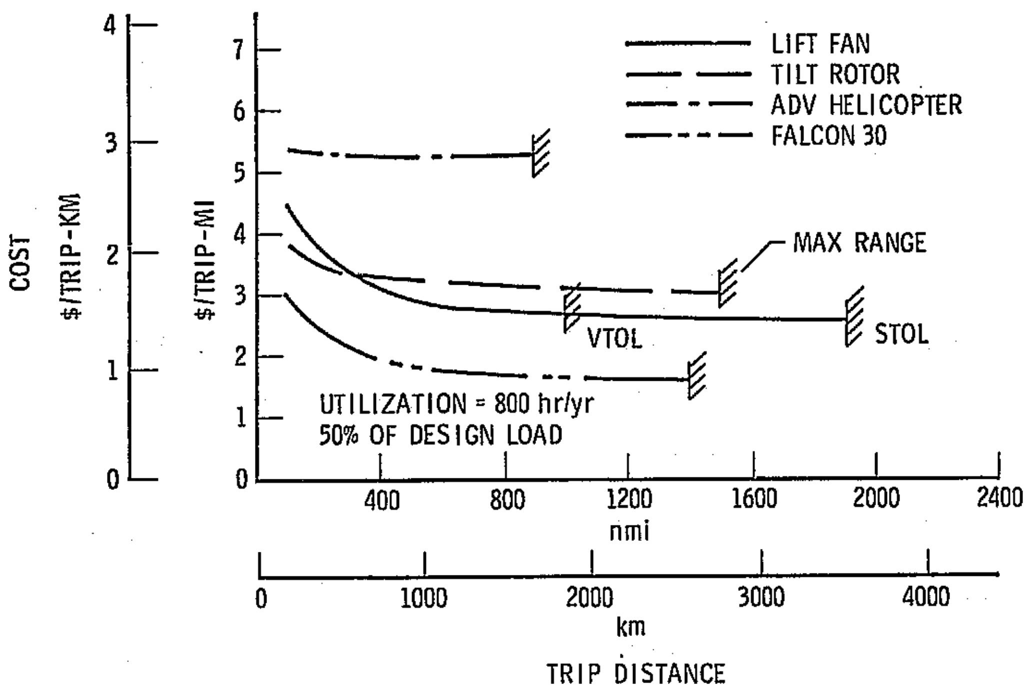

Figure 5-30. Cost Per Trip Unit Distance - Executive Mission

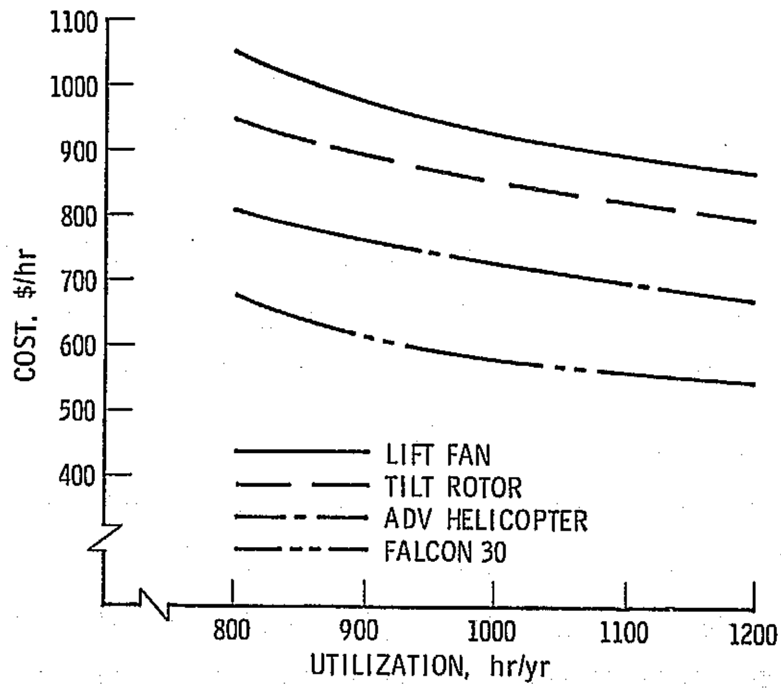

Figure 5-31. Executive Mission Hourly Costs as a Function of Utilization

spread over more miles. The analysis results shown were developed by assuming that the aircraft carried 50 percent of their design nominal passenger load (12 passengers for advanced concepts and 20 passengers for the Falcon 30). The aircraft takeoff weights are below maximum gross weights for the maximum range missions, even though they carry full fuel. For passenger loads less than these values, the costs per trip unit distance are slightly less. As noted on the figure, the values are computed by assuming a utilization of 800 hours per year. Seat mile or passenger mile costs for any range can be easily found by dividing the trip distance cost by the number of seats or by the number of passengers carried.

Figure 5-31 indicates the effect of utilization on the hourly costs of operation is as expected, the lift fan aircraft is the most expensive one on an hourly basis; but its high productivity, because of its speed, makes it more cost effective than the other advanced concepts, as shown in the curves of Figure 5-30 discussed previously. An annual utilization of 800 hours is assumed to be the practical minimum that might be expected for prospective Transport Mission operations of the advanced concepts.

The advantages of the advanced concepts are not simply that they can favorably compete in speed, cost, and range with contemporary jet aircraft performing this mission. One of their main advantages lies in their ability to take off and land in restricted space, such as the company's parking lot, or a rooftop heliport. Considerable trip time is consumed during the trip to the airport, the CTOL aircraft taxi and takeoff delays, traffic delays associated with approach and landing, and finally the delay from the airport to the place of business. Figure 5-32 attempts to place these delays in proper context[1] and shows the time advantages inherent in the VTOL concepts.

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[1] Those who feel that the fixed delay times should be other than those shown here may adjust the intersection of the appropriate aircraft lines on the ordinate of Figure 5-32 to conform with their own experiences.

The assumptions developed are shown in Figure 5-32 and in the subsequent analyses.

a. The VTOL aircraft were assumed to depart and land at the company heliports, and no time penalties were assumed since this is equivalent to going from the office to the parking lot to get transportation to the airport for CTOL travel.

b. The STOL lift fan was assumed to operate from a small general aviation airport. Twenty five minutes were added to each trip end to allow for the ride to/from the airport and transfer between the modes.

c. The Falcon 30 was assumed to operate from a transport airport instead of a major airline terminal. Forty five minutes were added to each trip end to account for the trip to the airport, the taxi and takeoff delays, approach and landing delays, and transfer between modes.

d. The airline timeline assumed that the major airport is less accessible than the airport used by the Falcon 30 and is more prone to traffic delays for both departing and arriving flights. In addition, passenger checking and baggage retrieval is a new factor injected, plus the need to operate with a buffer time to allow for ground mode contingencies. (It was recognized that a commercial airline will not wait for a passenger who has been delayed through circumstances beyond his control, but the company plane may wait under certain conditions. Thus, the executive need not always plan for ground mode contingencies when using his company's aircraft.) These considerations have led to the suggestion that one hour at each trip end would be a reasonable assumption. The average speed for the airline's aircraft has been established at 400 knots (206 m/sec), and all flights have been assumed "direct" (nonstop).

In Figure 5-32, it may be seen that, where airline service is available, the advanced helicopter saves time over the airline up to 300 miles (556 km). The Falcon 30 and the tilt rotor appear to be reasonable choices for approximately 1000 miles and 3000 miles (1852 km and 2408 km),

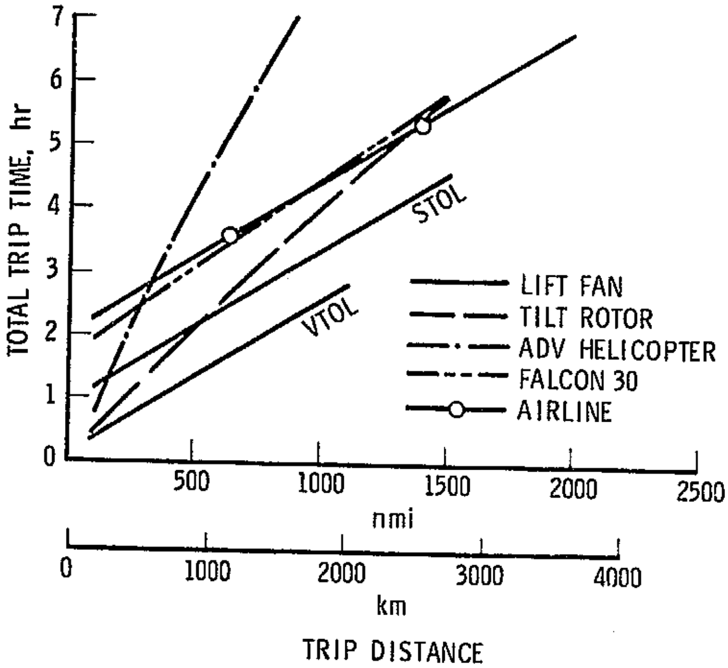

Figure 5-32. Trip Time as a Function of Distance and Aircraft Type

respectively. It may also be seen that the lift fan aircraft saves time over all concepts in the VTOL mode, and the lift fan aircraft as a STOL is, in the main, faster than the tilt rotor beyond 500 miles.

However, airlines do not provide access to all areas for corporate executives. Diversity in investment and industrial locations has resulted in corporate interests being dispersed throughout the country. Currently, the airlines serve only a small fraction of the smaller cities and seldom by direct flights. The effects of possible airline deregulation portend the further reduction of cities served by the major airlines, creating an even worse situation for the corporate executive desiring to travel to his dispersed business interests.

For the most part, airline travel is not germane to this analysis and is included here for comparison for those few cases where it is of interest. It can be said, in general, that, when the airlines serve the areas of interest with reasonable flight schedules and direct routings,

time will be saved by using the airlines for flights over 1500 miles (2778 km) instead of the executive aircraft. Even when the assumed full passenger loads are carried, the per-passenger costs for the advanced concepts greatly exceed the costs involved on the airlines. The Falcon 30, on the other hand, operates, fully loaded, at per-passenger costs below those of the airlines because of its greater seating capacity (20 passengers versus 12 passengers for the advanced concepts).

A more effective means is required to compare these aircraft with each other (and the airline), a means which accounts for the savings of time as well as taking into account the costs per passenger associated with each aircraft. If the value of the traveler's time is known, the total cost of any trip can easily be computed by adding to the cost per passenger the product of trip time and the travelers time value. It is difficult to evaluate a traveler's time value in universally acceptable terms; therefore, the value of the traveler's time is considered a parameter and the points of equal costs for two modes of travel may be computed (reference 11). This relationship is displayed in Figure 5-33.

In Figure 5-33, the advanced helicopter is compared with the airline. Three different airline situations are shown. The solid line indicates the combinations of trip distance and traveler's time value which result in equal costs for the airline and the advanced helicopter for the optimum airline schedule. This curve assumes that the helicopter trip is taken by 12 people and total trip costs are shared equally. (This is the limiting, least expensive case and certainly not typical.) It may be seen from the figure that the advanced helicopter is a reasonable mode choice out to a range of 200 nm (370 km) if the average traveler's time is valued at $10 per hour. However, if the time value is set at $40 per hour, the advanced helicopter may be a cost-effective choice out to a range of 280 nm (519 km).

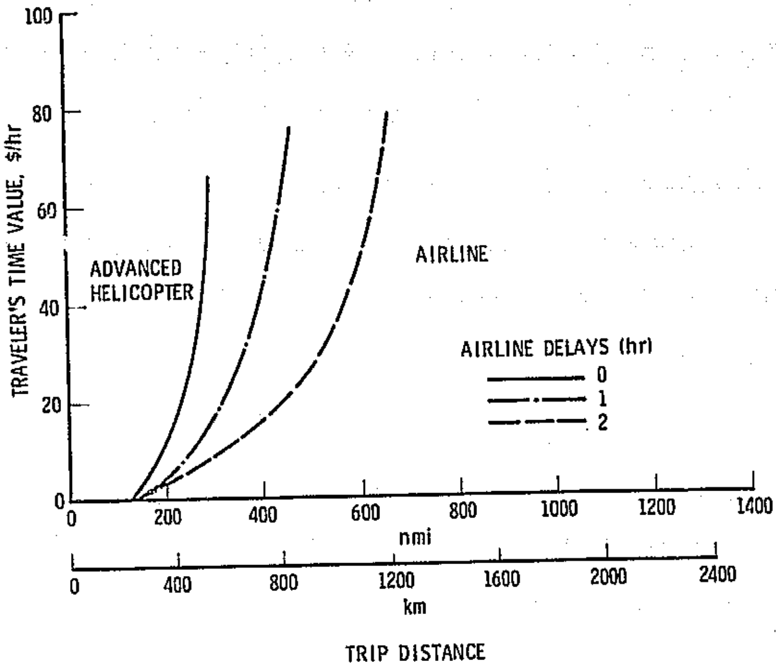

Figure 5-33. Advanced Helicopter vs Airline Phase Diagram

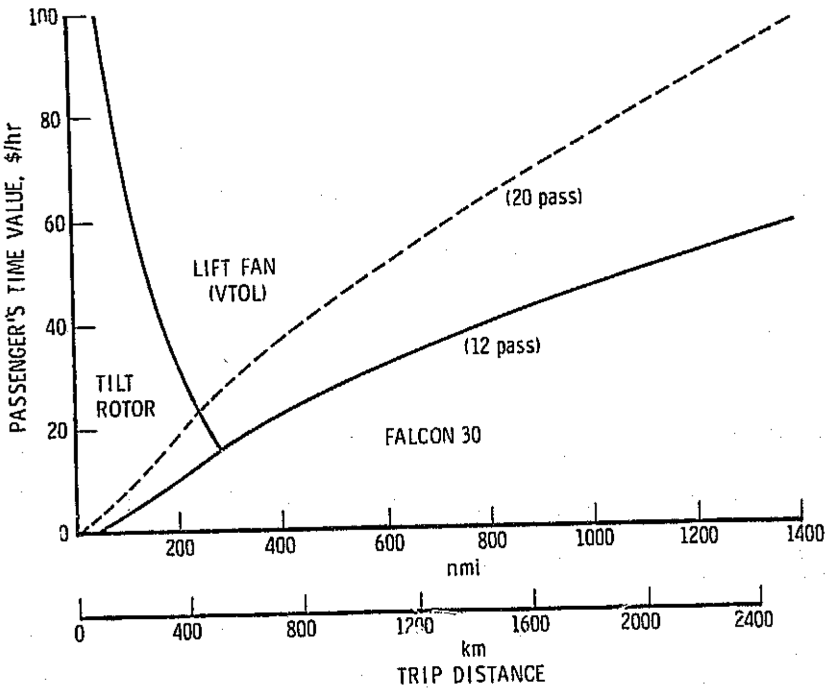

Figure 5-34. Composite Phase Diagram for the Executive Mission

The two broken lines show the effect of airline delays. These delays are associated with the need to change planes, en route stops, or may result from the incompatibility of the airline's schedule with the traveler's desired time to start his trip, thus causing additional travel time. For a traveler's time value of $20 per hour, the cost-effective range of the advanced helicopter is extended to 320 nm and 440 nm (593 km and 915 km) for airline delays of one hour and two hours, respectively.

Similar analyses were conducted, comparing all executive modes with each other and the airline. Figure 5-34 shows the combined results of these analyses. The Falcon 30 is seen to dominate the lower time values at almost all ranges because of its economy. This is true even though its passenger load is reduced to 12 people. (Since the advanced concepts were assumed to carry 12 passengers, computations for the Falcon 30 party size was also set at 12 passengers for standard cost comparison, instead of the previously assumed load of 20 persons in the executive configuration. If the party size is greater than 12 passengers, the Falcon 30 is the obvious choice since two advanced aircraft would be required to carry the travelers, and the double-operating costs would not be competitive.)[1]

Inasmuch as it was determined in previous studies that most executive trips for medium- and long-range lengths are in the range of 300 nm to 500 nm (556 km to 926 km), it may be concluded that the lift fan (VTOL) would be best suited for use if the traveler's time value is greater than $30 per hour.

For trips of generally shorter range (200 nm (370 km) and less), the tilt rotor is more favorable, except for the highest time value travelers; here, the lift fan again becomes desirable at about 100 miles (185 km), i.e., at a time value of $80 per hour.

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[1] The dashed line shows the effect of assuming 20 passengers in the Falcon 30 versus 12 passengers in the two advanced concepts.

The airlines, advanced helicopter, and the lift fan aircraft in the STOL[1] mode are all missing from the diagram since they are not found to be competitive in any way in this particular analysis.

In summary, this study found that the size of the aircraft studied was, generally, too large for the executive transportation mission currently being flown. Other significant findings of the study were the following:

a. The tilt rotor and lift fan aircraft are approximately 30 percent more expensive than the Falcon 30 to operate on a trip mile basis, and the advanced helicopter approximately twice as expensive as the other two concepts;

b. Out to their maximum ranges, both the tilt rotor and lift fan aircraft are competitive from the standpoint of time with the airline and Falcon 30. At short ranges, these two advanced concepts are twice as fast as either the airline or Falcon 30. The lift fan aircraft is consistently twice as fast in performing this mission than the airline or the Falcon 30;

c. The advanced helicopter is only time competitive with the Falcon 30 and the airlines to a range of 300 nm (556 km);

d. The tilt rotor is cost effective out to a range of 300 nm (556 km) for travelers whose value of time is approximately $15 per hour. For the lift fan (VTOL) to be cost effective at a range of 600 nm (1111 km), the value of the traveler's time must be approximately $30 per hour.

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[1] The STOL lift fan aircraft's savings in time is erroded by its greater cost than the Falcon 30, and the lift fan STOL cannot compete with the lift fan VTOL.

F. THE HUMANITARIAN MISSION

In the context of this study, humanitarian missions include those flights whose purpose is the saving of lives, or the relieving of human suffering. Specifically, missions which evacuate sick or injured, transport food, clothing, medical supplies, medical personnel, shelter, etc. to victims of any disaster affecting man are prime for consideration for the advanced concepts. With their speed, range, and payload capabilities, the advanced concepts studied can extend the role currently played by the helicopter. For the study vehicles to be of practical advantage, however, the demand must be for a VTOL machine with a radius of action of approximately 500 nautical miles, while maintaining a medium load carrying capacity. Many humanitarian missions may not require these general criteria, especially a payload capability of 5000 lbs. In this event, advanced concepts of the size examined here may be inappropriate since the missions may be effectively supported by slower, shorter ranged helicopters.

Since the purpose of this study was to examine missions for civil versions of these concepts, the basic assumption of the study that civil production was predicated on having military production, introduced a significant complication in this mission's analysis. It generally happens that large scale requirements for humanitarian air lift result in military aircraft being pressed into service temporarily. Therefore, it appears extremely unlikely that a commerical operator will purchase a costly machine on the chance that it may be employed should the occasion arise owing to disaster - especially knowing that the military can be expected to quickly respond with similar machines. On the other hand, it is of interest to see how competitive the study vehicles are under these mission requirements and to assess the possibility that one might be employed effectively should the situation arise.

1. CURRENT OPERATIONS

Little factual information on humanitarian missions was available for this mission analysis. Situations similar to the Guatemalan earthquake

Table 5-8 Advanced Concepts Humanitarian Mission Parameters (Per Flight)

Mission Segment	Time (Min)	Distance (nm)	Pass. (No.)	Cargo (lbs)	Altitude (ft)
Load	60	-	5	5000	-
Warmup	5	-	-	-	-
Takeoff	1	-	-	-	0
Enroute	-	500	-	-	5000[a]
Land	1	-	-	-	0
Unload	30	-	-	5000	-
Load	30	-	20	-	-
Takeoff	1	-	-	-	0
Enroute	-	100	-	-	5000[a]
Land	1	-	-	-	0
Unload	5	-	15	-	-
Refuel	30	-	-	-	-
Takeoff	1	-	-	-	-
Enroute	-	500	-	-	5000[a]
Land	1	-	-	-	0
Unload	5	-	5	-	0
Standby	60	-	-	-	-

[a] Minimum altitude

relief of 1976[1] are carried out under no particular jurisdiction; therefore, little or no data regarding the mission requirements are available. Attempts to obtain data on these missions were unsuccessful during this study. Because there appears to be no repository of statistical data or missions of the type desired, it was necessary to synthesize a mission for analysis.

2. MISSION DESCRIPTION

A hypothetical humanitarian mission was defined to examine the economic and operational performance of the study aircraft. The situation assumed for this mission is described in general by the following scenario.

A large disaster, such as an earthquake, fire or flood, occurs in a populated, but relatively remote area. The disaster renders all modes of ground and CTOL air transportation virtually useless. An initial emergency relief mission must be mounted to deliver medical supplies, personnel, food and clothing, and to evacuate injured inhabitants of the area. The mission requires the delivery of a total of 25,000 lbs (11,340 kg) of supplies and 25 people to the area. The main base, the location of the aircraft, the supplies, and people to be transported, is 500 miles (926 km) from the disaster area. Evacuation of injured is to be made to a town 100 miles (185 km) from the disaster area (location of an intermediate base). The more seriously injured are to be returned to the main base where more specialized medical facilities are located. Figure 5-35 depicts the nominal advanced aircraft mission in graphic form, while Table 5-8 provides the mission segments with their quantitative parameters on a per flight basis.

Both the lift fan and tilt rotor aircraft are capable of flying the round trip flight without refueling; however, the advanced helicopter is only capable of flying the first major leg plus the distance to the intermediate base without refueling. Therefore, a refueling segment was required at the intermediate base, and all aircraft were assumed to refuel there.

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[1] At the time of this writing a full understanding of this effort was not available.

The time associated with the loads, unloads, and refuel are felt to be conservative. In all probability, a well coordinated activity could be more efficient, but seldom is this the case in actual practice, and whatever inefficiencies there are tend to penalize all concepts equally. Also, it should be realized that no cost penalty was assumed for ground time while the engines were not running.

The range of the mission is beyond the effective range of most contemporary helicopters carrying any reasonable payload. Therefore, a variation on the mission was devised for comparison purposes. The mission variant assumed that a Falcon 30 delivers the supplies and people to the intermediate base. From there they are shuttled to the disaster area by a Sikorsky S-61. The Sikorsky was assumed to be based at the main base and must be ferried to the intermediate base. Since the distance to the intermediate base is at the Sikorsky's maximum range, no payload can be carried on the ferry trip. Tables 5-9 and 5-10 provide the per flight mission parameters for the Falcon 30 and S-61 portions of the mission, respectively.

3. MISSION ANALYSIS

The summary of the Humanitarian Mission analysis is shown in Table 5-11. In order to deliver the total 25,000 lbs (11,340 kg) of supplies and 25 personnel, it was assumed that the volumetric requirements would dictate five trips by the advanced aircraft concepts, while the Falcon 30 would require only four trips because of its larger cabin volume.

The top half of Table 5-11 shows the performance of the advanced concepts; on the left are the economic and operational performance per flight, while on the right are the total mission performance figures.

For a VFR flight (no alternate airport fuel required) and refueling at the intermediate base, it is possible for the lift fan aircraft to make the initial takeoff vertically; otherwise, it must operate as a STOL initially. It may be seen that not only does the lift fan aircraft complete the mission

Table 5-9 Falcon 30 Humanitarian Mission Parameters
(Per Flight)

Mission Segment	Time (Min)	Distance (nm)	Pass. (No.)	Cargo (lbs)	Altitude (ft)
Load	60	-	5	7500	-
Warmup	5	-	-	-	-
Taxi	5	-	-	-	-
Takeoff	1	-	-	-	0
Enroute	-	500	-	-	5000[a]
Land	5	-	-	-	0
Taxi	3	-	-	-	-
Unload	30	-	5	7500	-
Load	15	-	5	-	-
Refuel	0	-	-	-	-
Warmup	3	-	-	-	-
Taxi	3	-	-	-	-
Takeoff	1	-	-	-	0
Enroute	-	500	-	-	5000[a]
Land	5	-	-	-	0
Taxi	5	-	-	-	-
Unload	5	-	5	-	-
Standby	60	-	-	-	-

[a] Minimum altitude

Table 5-10 S-61 Humanitarian Mission Parameters
(Per Flight)

Mission Segment	Time (Min)	Distance (nm)	Pass. (No.)	Cargo (lbs)	Altitude (ft)
Load	30	-	0	4000	-
Warmup	5	-	-	-	-
Takeoff	1	-	-	-	0
Enroute	-	100	-	-	5000[a]
Land	1	-	-	-	0
Unload	15	-	0	4000	-
Load	5	-	20	-	-
Takeoff	1	-	-	-	0
Enroute	-	100	-	-	5000[a]
Land	1	-	-	-	0
Unload	15	-	20	-	-

[a]Minimum altitude

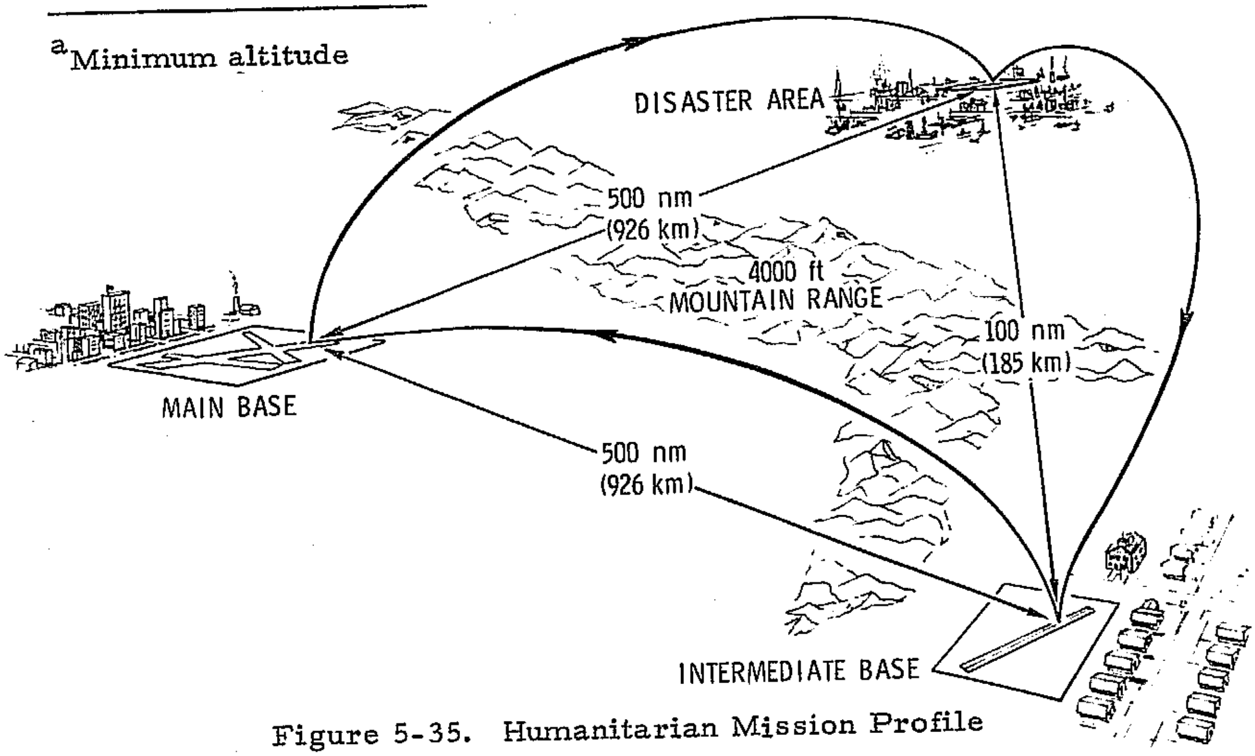

Figure 5-35. Humanitarian Mission Profile

Table 5-11 Humanitarian Mission Performance Summary

Aircraft	Per Flight Performance					Trips No.	Mission Performance			
	Elapsed Time Hrs.	Cost $	Cargo lb (kg)	Passengers			Total Time Hrs.	Total Passengers		Total Costs $
				Delivered	Evacuated[a]			Inter. Base	Main Base	
Lift Fan	6.64	2969	5000 (2268)	5	15/5	5	30	75	25	14,845
Advanced Helicopter	11.46	4810	5000 (2268)	5	15/5	5	51	75	25	24,050
Tilt Rotor	8.11	3083	5000 (2268)	5	15/5	5	37	75	25	15,415
Falcon 30[d]	6.57	1818	7500 (3402)	5	-/7	4	23	--	25	7,272
S-61 (Trip out)	4.7	2585	--	-	--		--	--	--	3,585
S-61 (Shuttle)	3.3	1148	3400[b] (1452)	3[b]	10/-	8	7[c]	80	--	9,184
S-61 (Return)	---	2585	--	-	--		--	--	--	2,585
TOTAL							30	80	25	21,626

a Intermediate base/main base

b Total of 4000 lb (1814 km) combined passengers and cargo permissible

c Subsequent to Falcon 30 last delivery

d A larger aircraft such as a Douglas DC-9 could perform the mission to the intermediate base making only one trip; however, this would not affect the total mission time since this is paced by the S-61 performance in the shuttle mission. The costs for the DC-9 would be in order of $6000.

more quickly, it also costs less than the other two advanced concepts. Mission completion is defined as unloading the last of the supplies at the disaster area base. Costs, on the other hand, include the cost of returning the aircraft to the main base. The tilt rotor is not much inferior to the lift fan aircraft in both time to complete and the total cost of the mission.

In the bottom half of Table 5-11, similar information is displayed for the CTOL/VTOL combination mission.

The Falcon 40 and S-61 are competitive with the lift fan aircraft time-wise; but with respect to costs, they are nearer the level of the advanced helicopter. The extra expense is related to the requirement to ferry the S-61 on a round trip. If the S-61 is assumed to be based at the intermediate base, the cost is reduced to approximately $16,500 and the time would be reduced by approximately two hours. While only five passengers per trip were assumed to be returned to the main base, a full load (20) could be accommodated without materially affecting the cost or time performance noted for any of the aircraft.

Since costs are possibly of lesser importance than speed in the performance of a mission where human life and suffering are involved, it appears that the lift fan and the contemporary mode performance are equal. The speed of the contemporary mode is paced by the productivity of the S-61 ferry time to the intermediate base, but once there it can make rapid turn-around shuttle trips, quickly reducing the cargo backlog placed at the intermediate base by the Falcon 30. The Falcon 30 only requires four trips to deliver its total cargo load because its volume is larger than the advanced concepts; however, the S-61 must continue to shuttle seven hours beyond the last Falcon 30's delivery.

Compared to the lift fan, the tilt rotor is approximately 20 percent slower while the advanced helicopter is about 70 percent slower than the lift fan. Actual missions in the future might consider the combination of the fixed-wing jet with a high-speed advanced helicopter as the most expeditious way to perform this mission.

Changing the range would have only small effects on the relative performance figures shown. Reduced ranges would not materially change the aircraft's standings. Extending the range would impact the S-61 ferry time and impose a disproportionate penalty to the contemporary mode. Ranges to the disaster area much beyond 600 nm (1110 km) would require that the advanced helicopter stop en route for refueling, limiting its effectiveness even more.

Other humanitarian missions were examined for possible application; however, these appeared to be of military orientation, i.e., Coast Guard, search and rescue, etc. Since aircraft operated by the military and the Coast Guard are generally not certified in the civil category, they do not favorably impact the civil production costwise, nor do they increase the civil market size. For this reason, these other humanitarian missions were deemed inapplicable to this study.

6. CONCLUSIONS

This study reported upon herein has examined the applicability of three advanced concept aircraft, sized for specific Navy Missions to the following four civil utility missions:

The offshore oil support mission
The forest fire fighting support mission
The (executive) transport mission
The humanitarian mission

The performance of all three advanced concepts is found to be superior to the contemporary aircraft used as a comparison for the offshore oil support mission. This is true in terms of range, speed, capacity, and costs. Contemporary aircraft used in the offshore oil support mission must compromise their passenger loads to meet the mission range requirements; even then, some contemporary aircraft are unable to meet the emerging range demands of this mission. This is not true of the advanced concepts studied. The range of all three advanced concepts, fully loaded, is sufficient to meet the general range requirements of world-wide offshore oil missions. In fact, when considered for this mission only, the tilt rotor and lift fan concepts could be redesigned for a shorter, approximately 800 nm (141 km), range, if this would benefit operating costs. In some areas of the globe (possibly southeast Asia), the lift fan aircraft or the tilt rotor would appear to be more desirable because their fully loaded range is more than twice that of the advanced helicopter. At these longer ranges, they would have an additional advantage over the advanced helicopter because of their higher speeds. On a seat-distance basis, the advanced concepts are found to be from one-half to one-third as expensive to operate as the contemporary aircraft. Because available seats are not strongly dependent on mission range, the cost per available seat distance is almost constant, or a slightly decreasing function, of distance for the advanced concept aircraft, while it is an increasing function of distance for contemporary aircraft which must offload passengers to obtain sufficient mission range.

The major concern in using the advanced concept aircraft for the offshore mission relates to their larger dimensions and weights compared to contemporary machines. It is possible that some problems may be encountered in making the landing pads of some existing rigs compatible with these larger advanced machines. Some pads may be readily modified at acceptable costs, while others may be impractical to modify from the standpoint of safety or economics. Without general use in the offshore oil mission, the full exploitation of these machines will be hampered.

By employing the advanced concept aircraft properly, they can effectively compete with contemporary aerial fixed-wing tankers and helicopters to deliver fire retardant materials. Because contemporary, fixed-wing aerial tankers are generally modified surplus military or commercial airline aircraft, they can operate inexpensively in a situation where a significant portion of the operating cost are aircraft depreciation spread over a relatively few flying hours. For new and expensive advanced concept aircraft to compete in this financial environment, their speed, capacity, and VTOL capability must be exploited to the fullest. This requires proper siting of fire control aircraft bases to permit fewer aircraft to cover a larger geographical area, and the development of equipment and techniques to permit the advanced concept aircraft to load fire retardants near the scene of the fir to minimize their turn-around time. When employed in this fashion, the advanced concept aircraft are found to be as effective and less expensive than contemporary aircraft performing the same mission. If mission planning includes the use of these aircraft on other compatible missions - on a noninterfering basis - the costs can be further reduced to the order of the older surplus aircraft used as aerial tankers. Under optimum employment conditions, the advanced helicopter and the tilt rotor operate at appxomately two-thirds of the cost of the lift fan aircraft; however, the lift fan aircraft's greater speed could represent a decided advantage when it comes to the question of deployment strategies. The tilt rotor's greater speed over the advanced helicopter would also be a definite factor in its favor when deployment is considered.

For the executive transport mission, the advanced concept aircraft must rely on a time advantage to find application. The time advantage must be important enough in relation to the time value of the executives being transported to offset the higher operating costs of these aircraft. Because of its slower speed, the advanced helicopter studied is not considered practical for this mission where it must compete with jet speeds and ranges. On a pure time basis, its advantages are generally limited to mission ranges below approximately 250 nm (463 km); however, when costs (including travelers time value) are considered, it seems undesirable for this mission. While it has time advantages, as compared with conventional modes, out to a range of about 1200 nm (2200 km), the tilt rotor can only compete with conventional jets and the lift fan concept out to a range of approximately 200 nm (365 km) when the time value of the passengers is considered. The lift fan aircraft concept exhibits a time advantage over its full range, and cost advantages for passenger time value of greater than approximately $30 per hour.

It should be noted that for the executive mission the advanced aircraft were assumed to be configured with twelve passenger seats. This was done since it was believed that the crowded conditions of their basic 23-seat configurations were incompatible with executive transport. Furthermore, a 23-passenger aircraft has a much larger passenger capacity than is generally associated with this mission. Comparisons were made with conventional aircraft of comparable size.

In fact, even a 12-passenger configuration may be too large for the executive transport mission. Most contemporary exectutive jets have smaller passenger capacities (e.g., the Sabreliner carries only 6-10 passengers). Should such smaller capacities be all that is needed, the advanced concepts should more logically be compared with smaller executive jets. The advanced concepts, of the particular size studied, would fare less well in such a comparison. However, if redesigned in smaller sizes, the advanced concept aircraft might still be attractive for this mission.

While it was beyond the scope of this study to examine aircraft of different size or performance characteristics, it was suggested earlier that the size aircraft examined appeared too large for some missions studied. This is not to imply that smaller aircraft are concluded to be more suitable for the spectrum of missions analyzed. For example, should the range of the study aircraft be reduced by approximately one-half as suggested earlier to better accommodate the needs of the offshore oil mission, the lift fan would find less favor in the executive transport mission because of its reduced range. The tilt rotor, on the other hand, was competitive with conventional jets and the lift fan only out to a range of approximately 200 n.m. for the executive transport mission. Hence a redesign for a reduced range of approximately 800 n.m. would not affect the extent of tilt rotor applicability for executive transport. For all the advanced concept aircraft, range reduction implies that the maximum take-off weight would be reduced, since less fuel would be required. This in turn would make the advanced aircraft less attractive for the forest fire mission since their load carrying capacity at the short range would be severely limited. Any attempts to define preferred sizes for these aircraft must necessarily entail detailed mission requirements analyses and appropriate considerations of requirements compromises.

It is apparent that a commercial aircraft operator would not expect the humanitarian mission to form a significant portion of his business considering its special nature, its infrequency, and the possibility of the military forces temporarily diverting their aircraft for this purpose. Nonetheless, this mission was examined to provide information on how effective the advanced concepts would be should they be employed in the manner described by a particular set of hypothesized parameters. The lift fan concept and the contemporary mode (a small jet transport working in conjunction with a medium helicopter) were essentially equal in terms of time, but the lift fan costs were approximately 75 percent of the contemporary mode's costs. The tilt rotor was only 20 percent slower in mission performance, and its costs were essentially equal to those of the

lift fan. The advanced helicopter was definitely outclassed. Compared to the lift fan, its time was 70 percent greater and its costs 60 percent higher. Although only examined at the one set of ranges, it may be concluded that the contemporary mode would tend to deteriorate some with regard to mission time and costs as the basic range increases beyond 500 n.m. (926 km) because of the increased ferrying time requirements imposed on the helicopter. Shorter ranges are not expected to materially change the standings of the aircraft examined. The costs associated with this mission are believed to be relatively insignificant in view of the mission's objective to relieve human suffering. If this is true, it may be concluded that the lift fan (in the size studied), and the contemporary mode (as defined herein) are equally effective for the mission defined, and the tilt rotor is only slightly less desirable.

Beyond the four missions studied, there are others which might be considered for the advanced concept aircraft, in the particular size studied or perhaps in other sizes. For example, the advanced concept aircraft could have applicability to missions currently flown by the Coast Guard. The use of the advanced concept aircraft for commuter or air carrier operations could be contemplated, though only if the need for the V/STOL capability could be justified. Some missions such as law enforcement, photography, and pollution monitoring did not appear to be applicable to these machines, primarily, because the size of the aircraft studied was too large. Smaller advanced concept aircraft would possibly find use in these missions. As mentioned earlier, smaller machines would probably find much greater acceptance in the executive transportation mission as well since, here too, the machines studied tended to be too large for the major market.

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